# Engineering Case Library

ECL 37 (A)

## ALLIED SOLID ROCKET CORPORATION[1] (A)

Mr. E. Addison, Head, Process Engineering Group of the Allied Solid Propellant Facility, received an inter-office memo in April, 1962, stating that Allied was bidding for the multi-million dollar "Algol" solid propellant rocket motor development program. The memo included a time schedule for completion of various phases of the program and for delivery of motors. Each motor included three cylindrical segments containing solid propellant and weighing 80 tons each. The function of the Allied Solid Propellant Facility was to mix the propellant ingredients and cast them into the segments.

One of the conclusions Mr. Addison drew from the memo was that the "premix" capacity of the Allied facility would have to be tripled to meet the requirements of the new development program. Premix is a viscous liquid containing ingredients of solid propellant. It was presently compounded in an experimental premix station, representing a capital investment of $180,000, and then transported to another station at Allied where other solid propellant ingredients (oxidizer and curing agent) were added. (A schematic flow diagram of the existing premix station appears as Exhibit 1A.)

Feeling the probability was high that Allied would win a contract for the proposed development program and that time would be at a premium for expanding plant capacity, Mr. Addison decided that engineering for the expansion should begin at once. He also decided to assign responsibility for expansion of the premix plant to Mr. Bill Gart, a recent engineering graduate who had been with Allied for eight months.

[1]Real name withheld by company's request


Prepared by Eugene J. Fisher of the University of Santa Clara in conjunction with the Stanford Engineering Case Program with support from the National Science Foundation

## Rocket Propellants

Rocket propellants in use today can be generally grouped in two categories: 1) liquid propellants, and 2) solid propellants. Rockets in the early days of rocketry, such as those built in the 1930's and 1940's by Dr. Goddard in the United States and by the Germans, primarily used liquid propellants such as alcohol and oxygen because they were readily available. Liquid propellants are also powerful, the specific impulse (pounds of thrust per pound of fuel per second) being 40% higher for some liquid propellants, such as hydrogen and oxygen, than for existing solid propellants. Also, with liquid propellants thrust may be varied during flight by throttling fuel and oxidizer flow.

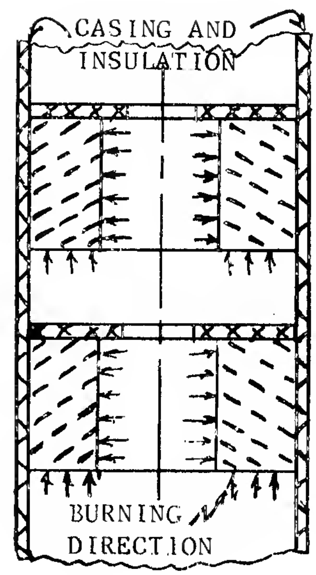
However, engineers were not entirely satisfied with liquid propellants for several reasons. First, some liquid propellant rockets such as those using liquid hydrogen and liquid oxygen must be fired soon after being fueled. The length of time between fueling and firing depends on the particular fuel and oxidizer system being used. Secondly, severe limitations are imposed on the material, handling and designing of liquid propellant rockets, because of the corrosion, explosion and fire hazards of the propellants.

Finally, liquid propellant rockets are generally more complicated and expensive than their solid propellant counterparts. Consequently, interest began to grow, particularly during the late 1950's, in the potentialities of large rockets powered by solid propellants. (Smaller solid propellant rockets had long been used as jet-assisted take-off (JATO) for aircraft and in lightweight, large caliber weapons, for example, the bazooka.) Some of the large, solid propellant rockets that followed were the Polaris, the Minuteman ICBM, and the Titan IIIC booster.

## Algol Booster

In the Algol solid propellant rocket booster, the propellant is cast in cylindrical segments, each segment having a thin steel outer shell twelve feet in diameter, a three foot inside diameter, and a length of twelve feet. The rocket is assembled by placing three segments, end to end, and adding a forward closure with igniter at one end and adding an aft closure with nozzle. One way to obtain a constant thrust is to keep the burning area of the fuel essentially constant. This is accomplished in the Algol booster by allowing each fuel segment to burn radially outward and at the same time burn upward towards the igniter, consuming the individual segments as pictured in the following sketch. Thus, as the diametral area increases, the length of the fuel segment decreases.

The solid fuel booster may not be stopped and reignited, as can the liquid fuel version; however, the exhaust gas direction of boosters may be altered by using liquid injections or "jetavators". With the former, a liquid is introduced at any of four equally spaced points in the expanding portion of the nozzle altering the direction of the thrust. With the jetavator, a ring is positioned behind the nozzle so that by rotating the ring, a portion of it enters the gas stream and acts as a "spoiler". This interference in the gas jet changes the direction of the thrust but subtracts from the total thrust force. The Algol boosters use liquid injector.




Propellant and Premix

The solid propellant used in the Algol booster consists of aluminum and an oxidizer suspended in a rubber-like solid. When ignited, the fuel and oxidizer burn in a highly exothermic reaction. To produce every one hundred pounds of fuel premix, twenty-nine pounds of prepolymer at 160°F in a highly viscous state, 5500 centipoise, are mixed with ten pounds of plasticizer, (similar in consistancy to water), in a large vessel called a reactor. The premix reactor must be waterjacketed and insulated so that it can be heated or cooled at will. Typically, there is a stirring machine similar to a food mixer, mounted on the reactor. Once the prepolymer and plasticizer are added to the reactor, the reactor valves must be closed, and the access hole sealed, so a vacuum can be drawn. This phase is referred to as "degassing" or the removal of dissolved gas during the mixing operation.

The three remaining ingredients are then added to the reactor. They consist of two pounds of liquid "cross-linker", one pound of burning rate catalyst and finally fifty-eight pounds aluminum powder. The fuel premix is then removed from the reactor and transferred to another station (one-quarter of a mile away in the case of the Allied Station) where solid oxidizer and epoxy are added just before the propellant is cast into a segment and causes the propellant to solidify on curing. The propellant segment is then cured for a number of days at elevated temperature.

Pilot Process

The existing experimental fuel premix station in April, 1960, consisted of a reactor and a large mixing device, known as Cowles Dissolver. Other equipment such as water heaters, cooling tower, pumps, scales for weighing ingredients, and finished premix, were located in the building adjacent to the reactor. Existing production capacity of the pilot process was one 56,000 pound batch every 50 hours.

Exhibit 2A shows the cycle for preparation of a 56,000 pound batch of fuel premix. Prior to the expansion of the premix facility, the PBAA/AN[1] (prepolymer) was loaded into the reactor by emptying 55 gallon drums through the upper access hole of the reactor. Accurate weighing devices were required to control the amount of material being added. Variation of the individual components in the batch had to be within plus or minus 0.3% by weight of the specified amount for the particular premix. The weighed amount of plasticizer was then poured into the reactor from a barrel. The upper access hole was then sealed by tightening the cover bolts with a wrench, and a vacuum was drawn on the reactor.

The mixing cycle began and the Cowles Dissolver operated for about six hours. Then a qualifying sample was removed from the batch. The sample was obtained by dropping a steel cylinder, about 1-1/2 inches in diameter and eight inches long, into the batch. The cylinder was equipped with a valve on either end so that once the level at which the sample was to be drawn was reached, the valves were opened by a wire trip. The material flowed into the cylinder as the air escaped from the top. The valves were then closed and the sample withdrawn. This sample was then sent to the qualifying laboratory, and if the ingredients were with the specified tolerance, the batch was "qualified".

When the batch had qualified, the remaining three ingredients, the cross-linker, the burning rate catalyst, and the aluminum (metal additive) were added through the upper access hole of the reactor. This loading took about sixteen hours, as reflected in Exhibit 2A. The aluminum was received in 400 pound barrels and a total of 82 barrels had to be elevated fifteen feet by a forklift to the access hole and emptied by hand for each 56,000 pound batch of premix. (See Exhibits 3A and 4A.) The dissolver was operating during the addition of these three ingredients.

Mixing continued for two hours after the last aluminum was added. If then the batch did not qualify, adjustments were made by adding ingredients that were low or by increasing the mixing time if the premix were not homogeneous. When the 56,000 pound batch was finally qualified, it was pumped to a weighing station and moved to the propellant mixing station, by tank truck at the rate of 3,000 pounds per hour.

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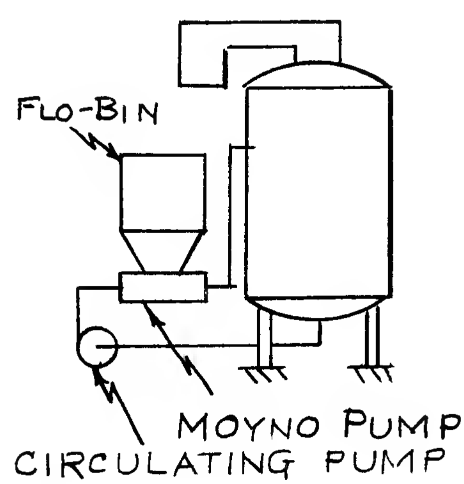
[1] PBAA/AN - Polybutadiene Acrylic acid Acrylic nitrile terpolymer - A binding agent for the metal additive and oxidizer in solid rocket propellant.

Background of Mr. Bill Gart

Mr. Bill Gart joined Allied as a process engineer in 1961. His previous experience had included studies at the University of California (B.S., Ch.E., January, 1961) plus two summers during college and a year after college engaged in process engineering. For the most part, this work involved computer studies of empirical equations that related output of a particular process to variables such as pressure, temperature, mixing rate, etc. By changing a particular variable, its effect on the process equation could be determined. After many iterations, the optimum values of these variables could be selected to maximize output, as measured by the particular empirical equation, at the same time minimizing operating time and cost.

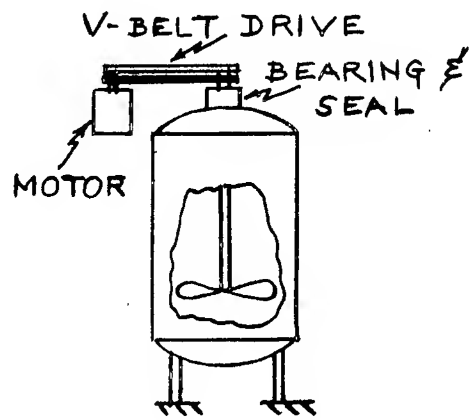
When Bill first joined Allied, he was asked by Mr. Addison to study the cycle of the premix operation and try to improve the mixing process. He was also to familiarize himself with machinery of the plant with the objective of eliminating any problems. During the next few months, a number of mechanical problems had come to Bill's attention. One day, for instance, Bill was surprised to find the reactor out of commission for repairs to shaft seals on the Cowles Dissolver. This mixing machine was, he found, the largest of its kind in the country, costing $20,000 and having a five month delivery time. To deal with emergencies such as the shaft seal failure, Allied stocked critical spare parts such as belt drivers, bearings and seals. Bill inquired about down time to replace the seal and learned that two days would be required at most. The cause of the problem was found to be that the shaft would "whip" if the mixer were operated with the reactor less than one-quarter full. The dissolver operated at 200 rpm and must operate as long as there is any premix in the reactor, but it need not operate if the finished batch is simply being pumped to a holding tank since the metal additive will not settle appreciably in a period of two to three hours.

During this same period, Bill became intrigued by several ideas for reducing the time for the total batch cycle by reducing the sixteen hours necessary to add the aluminum. It had been apparent to him as he observed men loading the reactor that there could be a significant saving in loading time because eight-two, 400 pound barrels had to be weighed, elevated to the loading platform (See Exhibit 3A), and then emptied manually into the reactor, as the dissolver was operating, for each 56,000 batch. Bill discussed some of his ideas with Mr. Addison. One would be to use larger containers, Flo-bins, (See Exhibit 5A) with a hoist to raise them to the access opening on the reactor. An advantage of this plan was that only seven



bins would be required per batch since each bin would hold 5,000 pounds of aluminun. Another advantage was that the Flo-bin could be "sealed" to the access opening so that aluminum dust would not escape and become a hazard to the operators. However, a weakness of Bill's scheme was that a high initial capital investment would be required for the hoist itself and also the existing building would have to be modified to accommodate the hoist.

If a pump could be used, the Flo-bins would not have to be elevated to the loading platform. Mr. Addison suggested that Bill investigate the possibility of using a "Moyno" type pump (See Exhibit 6A) to circulate the PBAA/AN plasticizer while adding the aluminum from the Flo-bins. Mr. Addison recalled using this type of pump to solve a similar mixing problem in a copper concentrator in Nevada. Bill contacted the Moyno Pump Company representative, Mr. C. W. Bosgood, who agreed to see Bill concerning the application of the pump.




Once Bill had described the proposed application of the pump, Mr. Bosgood said he was confident that the pump would "fill the bill" and agreed to furnish a smaller pump of the same type to be used in a quarter size model verification test. This test, Mr. Bosgood said, would supply information such as power required to introduce the aluminum, wear rates on the pump stator, length of time to load the metal additive, etc. Mr. Bosgood recommended the use of a Buna N (soft rubber) stator. Bill discussed the proposed tests with Mr. Naylor of Facilities Maintenance, (Allied), to get his recommendations. Mr. Naylor was doubtful about the useful life of the Buna N stator and expressed this feeling to Bill who then decided to test a neoprene stator and a silicon rubber stator in addition to the Buna N stator. Upon the completion of the pump tests, Mr. Bosgood was confident that the Buna N stator would last and offered, in writing, to furnish all the necessary replacement stators, in excess of one hundred dollars, free of charge, for one year's production of premix. This satisfied all parties concerned.

Bill stopped at Mr. Addison's office to inform him of the successful series of tests on the Moyno Pump and to discuss addition of a full scale model pump to the existing premix station. At this point, Mr. Addison informed Bill of the interoffice memo he had just received and said he had decided that the capacity of the premix pilot station would have to be tripled. Mr. Addison said, "Bill, you have been doing a good job with the premix facility for the last couple of months, so I would like you to be the project engineer in charge of the expansion program. You should

have the 'Design Criteria'[1] ready in about three weeks; in the meantime, keep me informed of your progress. Incidentally, I like the idea of the Moyno Pump. Try to incorporate it in the expanded station."

Expanding the Pilot Premix Station

Bill noted from the memo that two basic changes were to be effected in the pilot plant operation. One was to increase its capacity threefold and the other was to change from "batch" processing to continuous output at 3000 pounds per hour, three shifts per day, five days per week. He did not anticipate any great difficulty in planning this expansion, as he observed, "It is much simpler to enlarge a process that is already in operation than to design and layout a completely new process."

He began by listing individual pieces of equipment needed for the expansion and found that most of his investigations previously aimed at improving efficiency were directly applicable to the expansion. For instance, Bill was confident, based on the quarter-scale pump test results, that the full-scale Moyno pump installation would reduce the time necessary to add aluminum from sixteen hours to four hours. Another possible improvement that Bill had studied during the previous weeks was the use of positive displacement pumps to load PBAA/AN into the reactor. This change would also reduce the original cycle time, (See Exhibit 2A). By these changes Bill deduced he would be able to increase output of the pilot premix station from about 1040 pounds per hour to about 1700 pounds per hour. The expansion of this premix facility would then have to be practically doubled to reach 3000 pounds per hour.

Bill reasoned that there would be many ways that the production of this station could be doubled. For instance, he could recommend an identical station next to the existing one, duplicating all the facilties such as heat exchangers, pumps, reactors, dissolvers, cooling tower, controls, etc. Another solution would be to use an additional storage reactor from which the premix could be dispensed at the rate of 3000 pounds per hour as the existing reactor processed another "batch". Finally, an in-line blender might be used to furnish continuously the ingredients to the pilot premix reactor, from which the premix might be withdrawn at the rate of 3000 pounds per hour. Having reduced the possible solutions to these three, Bill continued to study the advantages and disadvantages of each.

Bill listed possible solutions and then discussed the pros and cons of these with Mr. Addison. As he "blocked out" these possible solutions, he was able to estimate flow-rates, headloss, pipe size, scale size, etc., for each possible solution.

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[1] In the company's vernacular, "Design Criteria" consisted of a written description of the process and the equipment necessary to create and materialize a product, complete with written plans for engineering and fabrication of a product, including figures on specific details, such as temperature limits, viscosity, controls, approximate location of major items, such as heaters, reactors, weighing devices, etc.

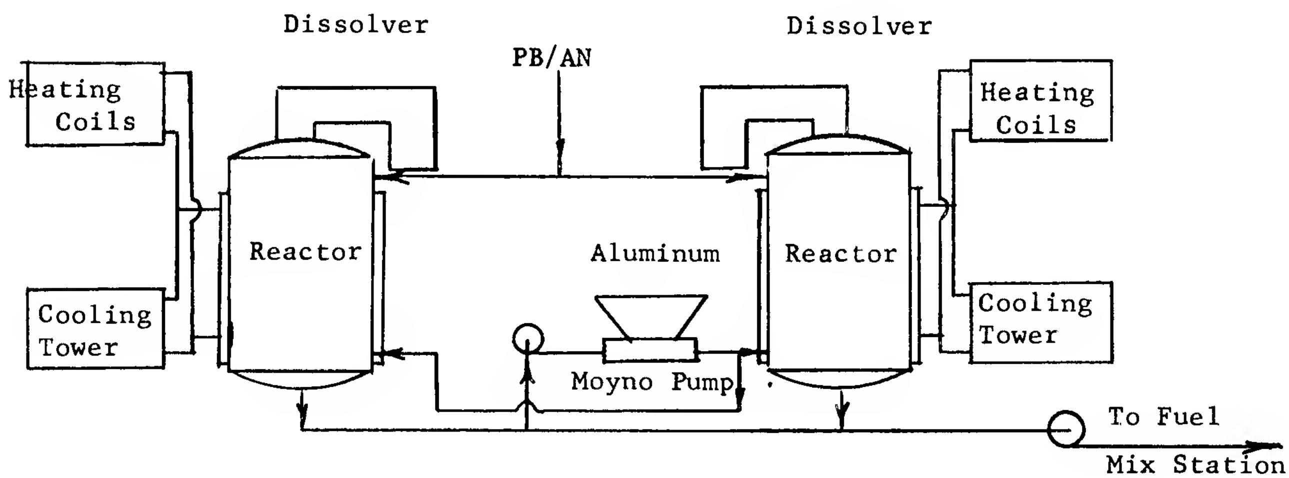
Process Evaluation

Further details of the three alternatives were as follows:

1) Add another dissolver and reactor.

This alternative would result in practically doubling mechanical equipment in the existing pilot premix station. One saving that could be effected would be to use only one Moyno Pump and weigh station for the addition of the aluminum since one reactor would be discharging premix while the other reactor was mixing a new batch. This system is shown schematically below. Bill estimated the engineering time to be about six hundred hours for this alternative.

SCHEMATIC OF DUPLICATION OF PILOT PLANT FACILITIES

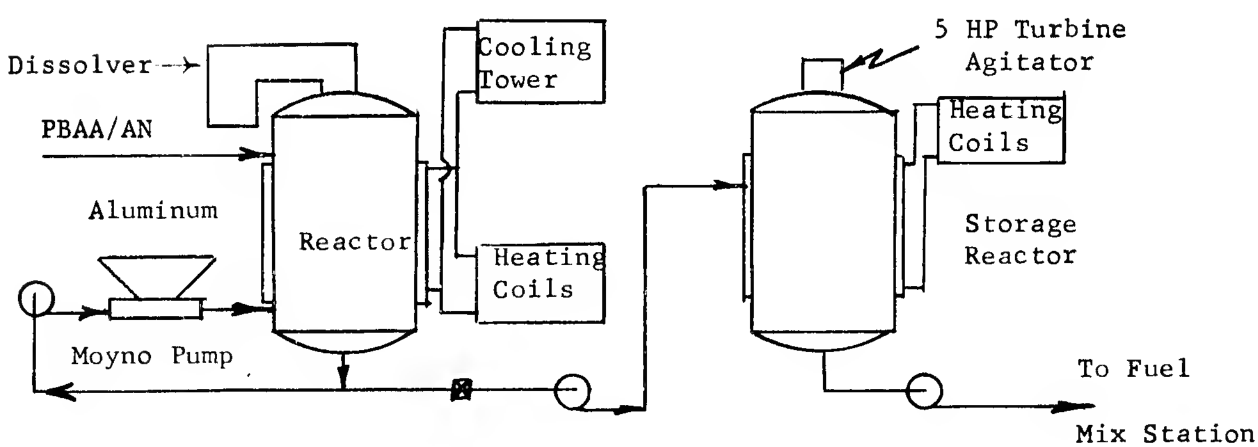



Regardless which alternative was selected, a certain amount of capital investment and engineering time would have to be spent to increase capacity of the heat exchangers which maintain the temperature of stored PBAA/AN. The capital investment and engineering time for this storage and mechanical equipment would, Bill expected, be identical for all three alternatives.

2) Add a jacketed premix storage reactor with an inexpensive turbine type agitator.

Bill had contacted Mr. Frank Milton, who represented Mixing Equipment Company. Bill realized that a large mixer, similar to the Cowles Dissolver, was required to mix the aluminum with PBAA/AN but once the aluminum and PBAA/AN were mixed, the power needed to keep the aluminum in suspension was much less. Bill then reviewed his second proposed process with Mr. Milton; this was to add a jacketed storage tank and associated equipment that would be capable of maintaining the temperature of the completed batch of premix as it was removed at the rate of 3000 pounds per hour. Mr. Milton proposed a five or ten HP @ 50 rpm turbine type agitator costing about $3,500, (See Exhibit 7A), for use in this plan.

SCHEMATIC OF A STORAGE VESSEL AND AGITATOR




Mr. Addison agreed with Bill that the idea of a storage vessel with a turbine agitator was a good solution if the material could be maintained in suspension. This solution would be more expensive than the in-line blender as far as initial capital investment was concerned; however, Mr. Addison observed that it would be about $16,000 less than the cost of two dissolvers and associated equipment. But he did express some doubt that a 5 HP @ 50 rpm agitator would be adequate to keep the premix homogeneous.

Mr. Milton immediately offered to run some mixing tests in the laboratory if Bill would provide the material and personnel to supervise a scaled down test similar to the test Bill had performed with Moyno Pump. Further, Mr. Milton stated that the Mixing Equipment Company would guarantee the process; that is, if the agitator failed to keep the metallic additive in solution, the Mixing Equipment Company would furnish to Allied free of charge an agitator that would do the job. The estimate of engineering time for this alternative was four hundred hours.

3) Add a small, in-line blender to premix ingredients and pipe this directly to the existing dissolver which would then act as a blender from which the premix could be drawn at the rate of 3000 pounds per hour. The in-line blender would operate like a blender used in a kitchen. The ingredients would be fed into a manifold as depicted in the schematic. These ingredients would then be mixed by an agitator similar to the propeller of an outboard motor as they flowed from the manifold towards the reactor.

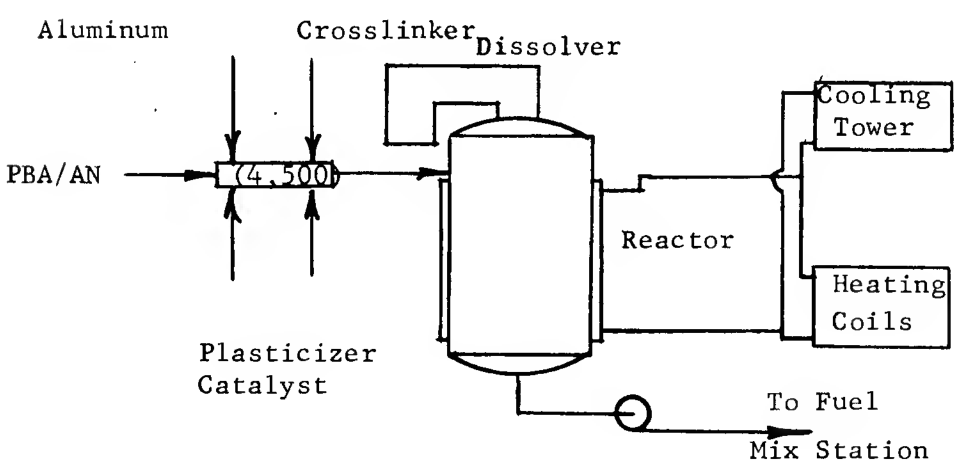
Since the ingredients would be added continuously, a constant weighing device would be required that would operate within plus or minus 0.1%. The total tolerance allowable, such as operator error, etc., would have to be equal to or less than plus or minus 0.3% by weight.

Discussing the continuous process with Mr. Butler, a sales representative for a scale manufacturer, Bill was assured that scales were available that would operate within plus or minus 0.1%; however, there would be a long lead time necessary for delivery. Mr. Butler also explained that there would be several sensitive interdependent adjustments to be made once the scales were installed, and these adjustments might take two or more weeks of operating time once the premix plant was "on the line". Mr. Jim Scott, a facilities engineer working with Bill on the expansion problem, observed that there would be a minimum capital outlay for the continuous in-line blender since the present building would need little or no expansion to house the added equipment. The blender itself would be only $4,500 investment; however, Jim readily agreed that weighing of material to be combined in the blender would be difficult to control and would require "advancing the State-of-the-Art" of mixing. That is, this blender had not been used in a similar situation to mix material within the required tolerance of plus or minus 0.3% by weight.

At this point, Bill interrupted Jim and said, "Let me relate one of my early engineering experiences. While assisting an engineer who was calibrating a process that involved mechanical devices, such as valves, mixers, weighing machines, etc., in the summer of 1959, we were able to achieve plus or minus 0.1% tolerance by careful adjustment of all the devices involved. This was the value that the manufacturer had stated would be obtainable. However, this performance required the engineer or myself to be present in order to make the continual adjustments.

"I have discovered," Bill continued, "that in order to operate continuously with little maintenance and perform within a specified tolerance, one should use an equipment tolerance that is a factor or two greater than the value stated by the manufacturer as attainable." Jim agreed that Bill had a good point, especially since adjustments similar to those to be made on the continuous blender would have to be made by an engineer.

<u>SCHEMATIC OF IN-LINE BLENDER</u>



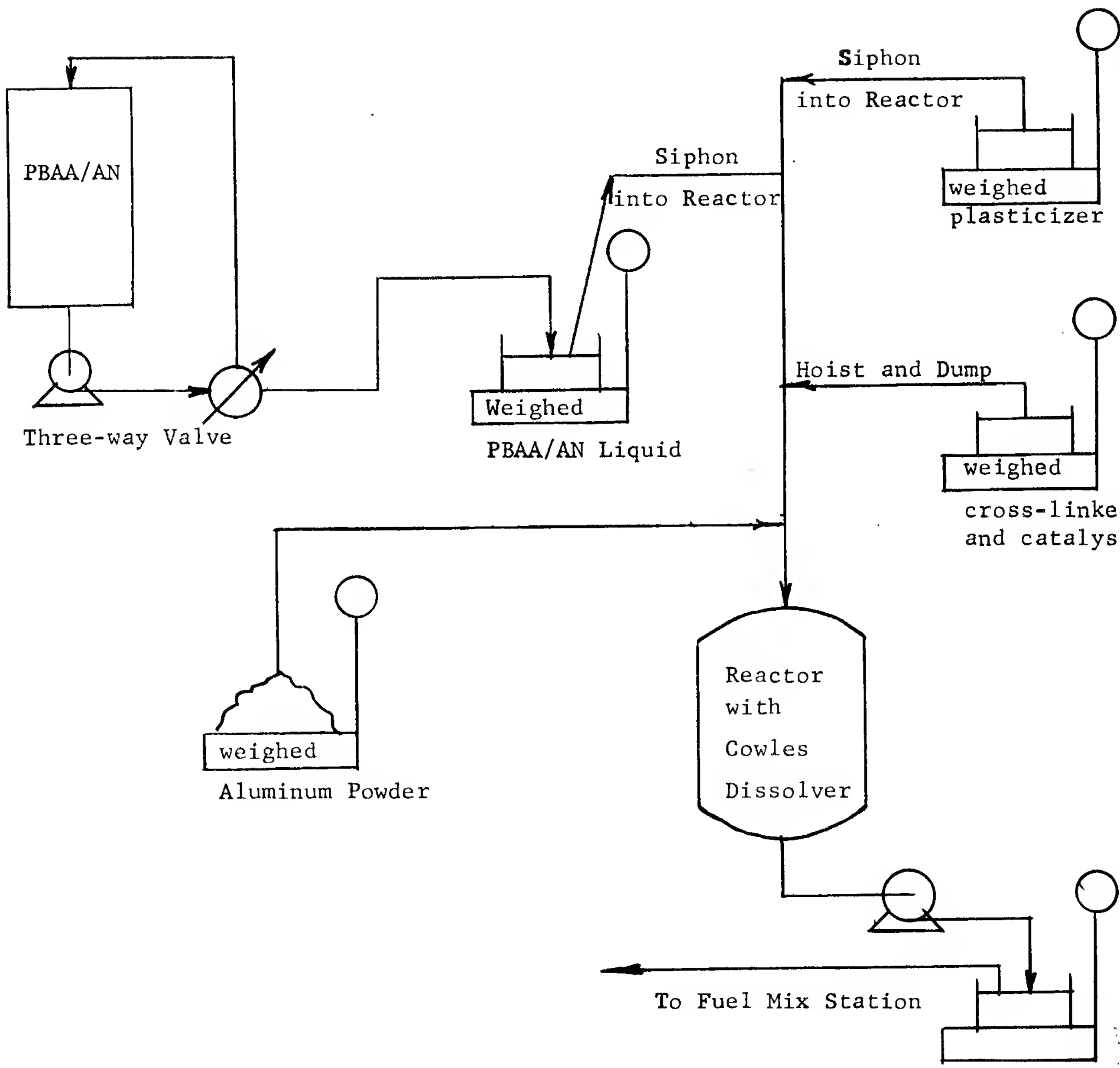
Since this continuous process would have to include some type of automatic, continuous weighing device, it would also have to include a feedback loop so that the appropriate corrections could be made if the weight of any of the individual components were greater or less than the premix tolerance allowed. Whoever had to make the adjustment would also have to understand the entire mixing scheme so that if a certain adjustment were made, the effect of this adjustment on the entire mixing operation would be anticipated. This would be expensive maintenance.

The estimated additional cost of the continuous weighing device for the in-line blender, as compared to the first two alternatives, was $7,000. Bill estimated the engineering time to be two hundred hours for this alternative.

Jim Scott had prepared a cost schedule for Bill on the three possible solutions, reflecting the delivery times and the cost of the major items, such as pipes, valves, pipe insulation, etc. Jim favored the third solution of the in-line blender since it required the least initial capital investment and allowed the facility to be designed by the Facilities Engineering Section of Allied. Bill admitted that having the design done by the Facilities Engineering Section would be an advantage since it would be easier to make slight changes as the design progressed. It would also be easier to keep "track" of the program as it developed, since it would be "in house". Mr. Dan Bensen who was in charge of this section explained that the Facilities Engineering Section would not be able to handle a relatively large design problem such as the storage tank and agitator because this Section was already involved in the expansion of two other facilities. Dan stated that the design and engineering of the first or second of Bill's proposals would have to be done by a consulting engineering firm. The cost of engineering time would be about the same, twelve dollars per hour, including overhead, whether the "engineering" was performed by Mr. Dan Bensen's section of Allied or by a consulting engineering firm.

Bill was preparing the final draft of the Facilities Criteria which had to be presented to Mr. Addison in two days. As Bill began to write, he pondered the ramifications involved. Certainly, the use of two identical dissolvers would be the simplest expansion solution as far as making sure that the process machinery would operate properly. The second and third alternatives were not so reassuring, however. Mr. H. Hale, in charge of maintenance, had informed Bill that even a major repair such as rewinding the motor on the Cowles Dissolver could be accomplished in twenty-four hours. Mr. Addison had informed Bill that the cost of "down time" on the premix facility would be $120 per hour. This reflected only the fixed cost of operation of the station. Still musing, Bill said to himself that an engineer doesn't continue to climb in any organization if he makes erroneous decisions. Yet he thought an engineer should not hesitate to try a different approach if he has evaluated it and is confident that the "new" approach would accomplish the objective and would effect a cost saving.

SCHEMATIC OF EXISTING PREMIX STATION




PBAA/AN - Polybutadiene Acrylic Acid Acrylic Nitril Terpolymer.
(A binding agent for the metal additive and oxidizer in solid propellants.)

| Material | Physical Form | Remarks | Present | Proposed |
|---|---|---|---|---|
| PBAA/AN (Prepolymer | Viscous liquid | pump to reactor | 7 | 2 |
| Plasticizer | Viscous liquid | siphoned | 1 | 1/2 |
| Degas and Qualify Cross-linker | Liquid | load | 7.5 | 4-1/2 |
| Burning rate catalyst | solid | load | 1/2 | 1/2 |
| Aluminum Powder | | load | 16 | 4.5 |
| Mix period | | | 2 | 2 |
| Qualify | | | 1 | 1 |
| | | TOTAL TIME (HOURS) | 35 | 15 |


Loading Platform
Vee Belt Drive
Motor
Reactor

Exhibit 4A

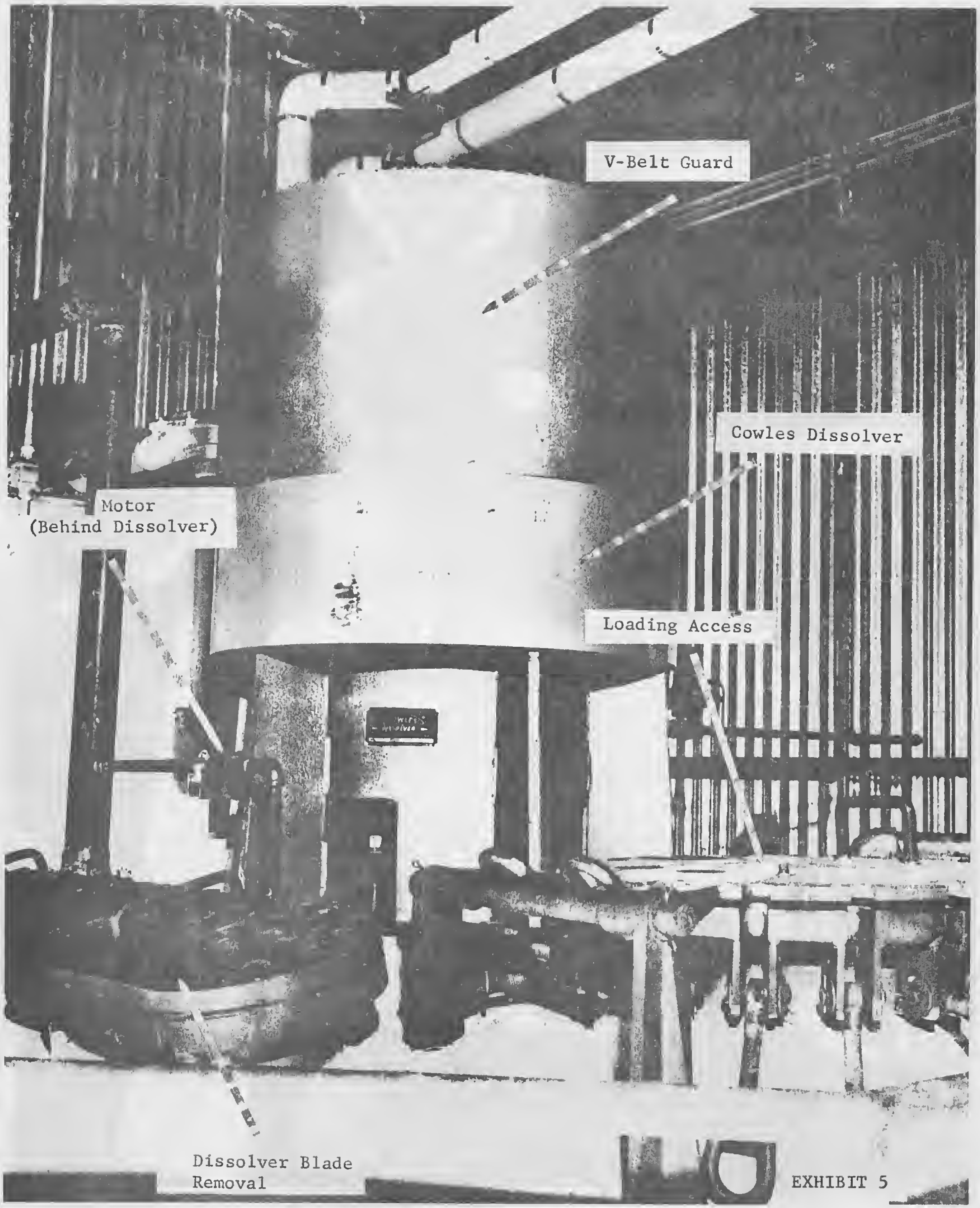
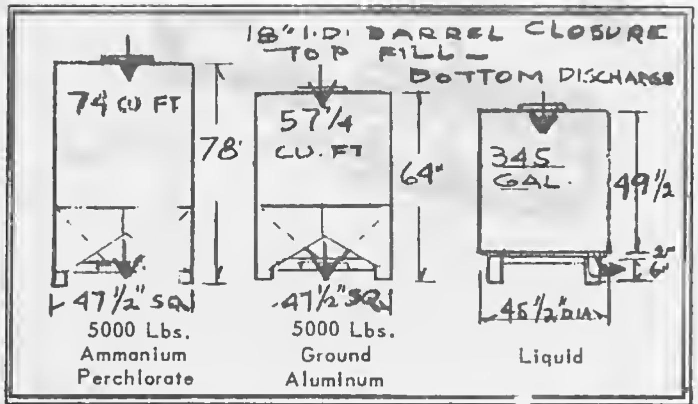


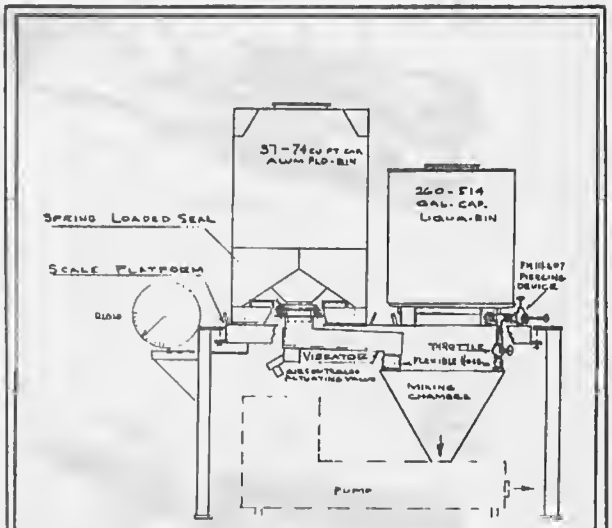

EXHIBIT 5

ECL 37 (A)

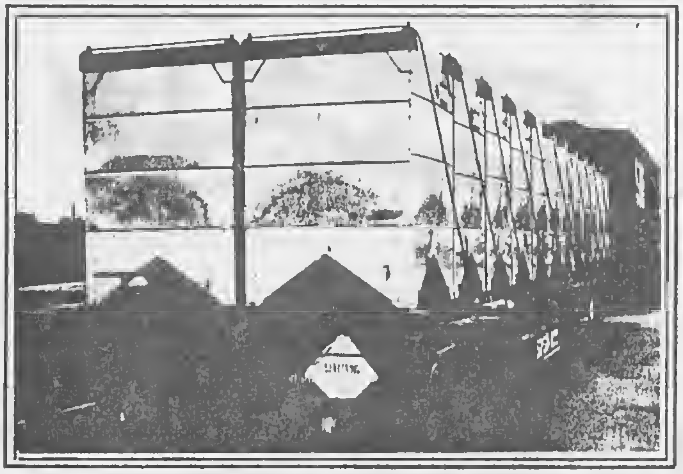
Exhibit 5A

# FLO-BINS




BULK DRY AND LIQUID UNLOADING



LOADED CONTAINER CAR

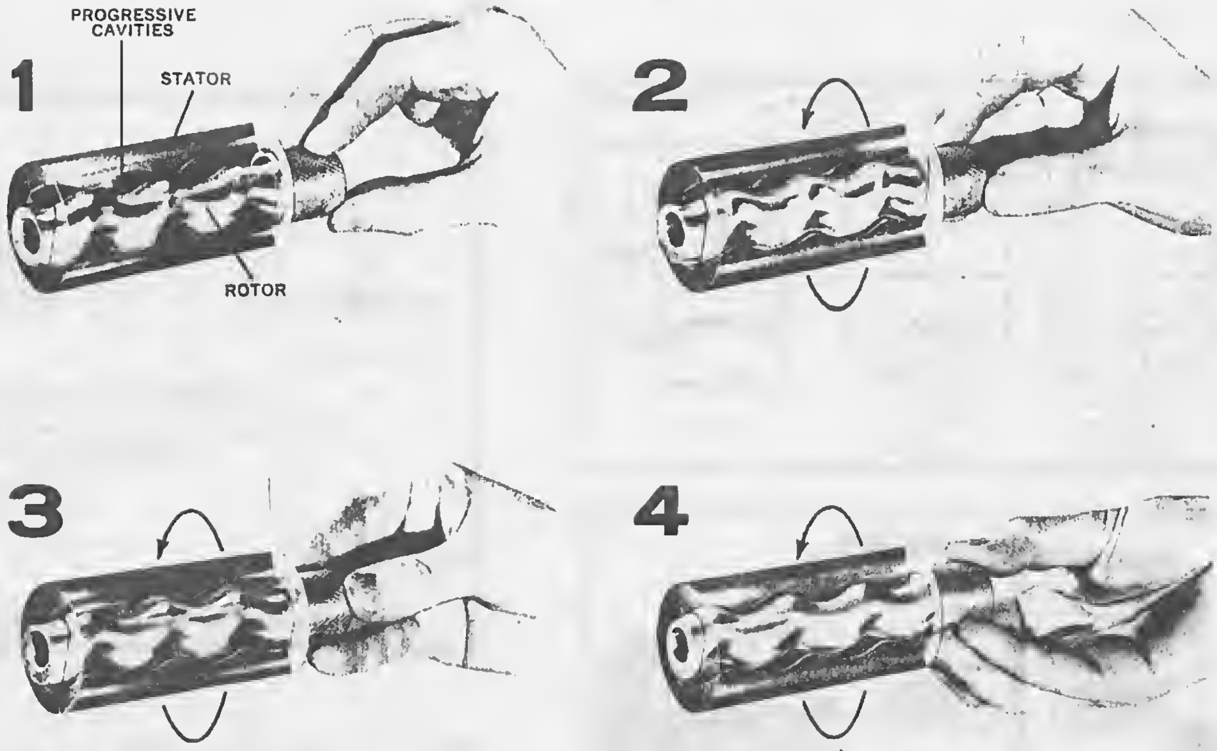
Shown are the FLO-BINS for solids and liquids, the container car for transporting FLO-BINS, and a schematic diagram of the bins unloading into process by weight or volume.

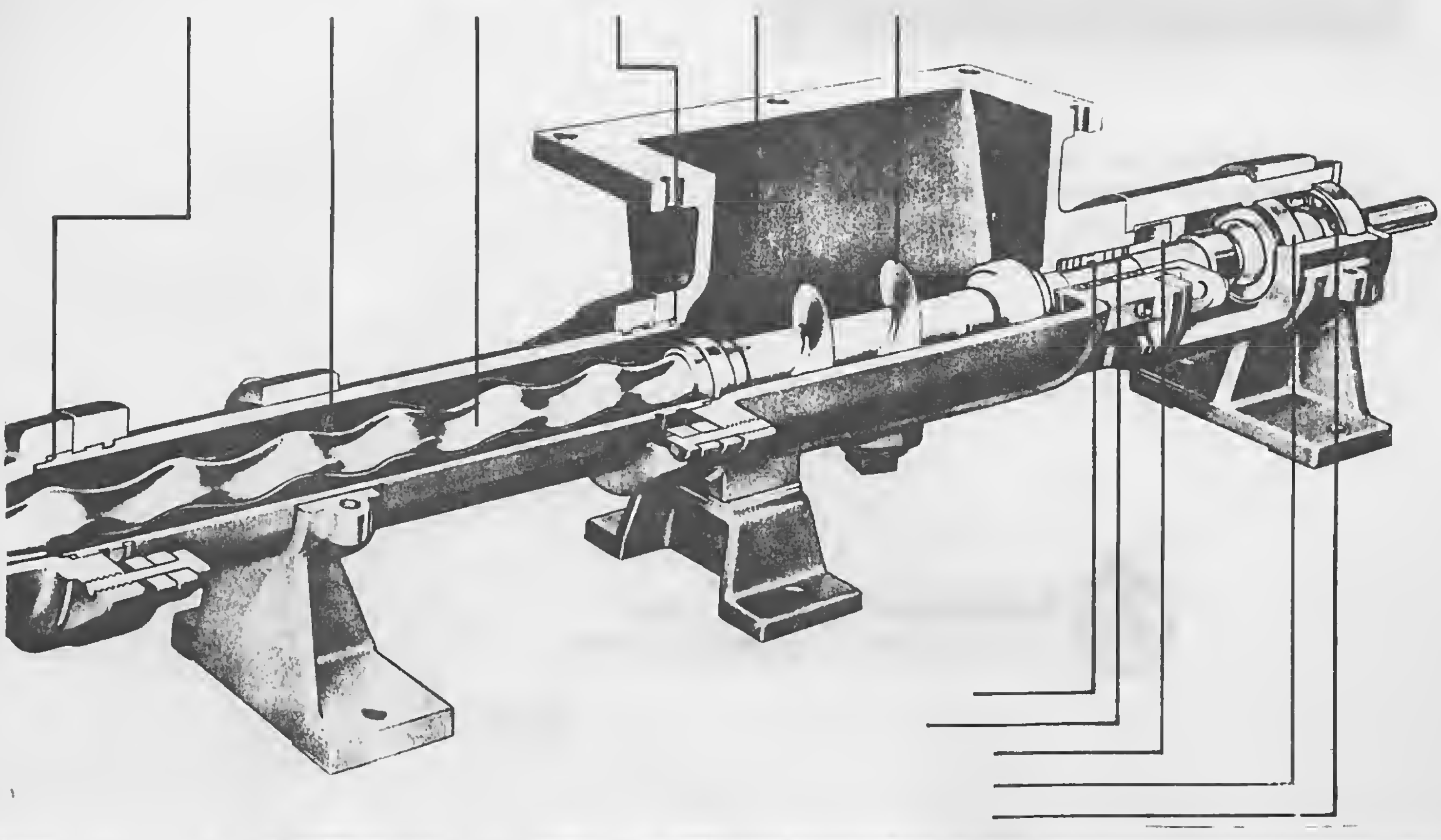
The containers are top fill, bottom discharge, constructed of aluminum or heavy sheet steel, galvanized after fabrication.



Exhibit 6A

Exhibit 6A



ECL (A.
Exhibit 7A

# Lightnin® Mixers

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**MIXING EQUIPMENT CO., INC.**
**217 Mt. Read Blvd. • Rochester 3, N. Y.**

Exhibit 8A

## REFERENCES

1) M. J. Zucron, Aircraft and Missile Propulsion, Volumes I and II, John Wiley and Sons, Inc. 1958.

2) G. P. Sutton, Rocket Propulsion Elements, John Wiley and Sons, Inc., 1963.

# ALLIED SOLID ROCKET CORPORATION (B)

Mr. Bill Gart had submitted the Design Criteria[1] to Mr. E. Addison, Chief Process Engineer (Allied), on a Wednesday morning. On Thursday afternoon, an informal meeting was held at which Mr. Addison, Mr. P. Parson, Manager of Corporate Facilities, and Mr. Bill Gart, Project Engineer - Premix Facility Expansion, met to discuss the Design Criteria that Bill had developed. Mr. Addison concurred that Bill had selected the proper alternative (See Part A of this case) when he had decided to employ a storage tank with turbine type agitator for the expansion of the fuel premix station.

The consulting engineering firm of Gurney and Tost was selected by Mr. Parson to perform the design and layout of the expansion of the existing premix facility as dictated by the Design Criteria. This firm had performed the engineering design for the original premix facility and Allied was satisfied with the results.

About six weeks later, the firm had proceeded to the point where a heat exchanger had to be selected. A general view of the Premix Facility appears in Exhibit 1B. Two proposals were submitted by manufacturers of tubular heat exchangers, and Mr. Gurney assigned a design engineer, Mr. Robert Olsen the task of checking to see if these heat exchangers were the proper size. One heat exchanger would be used to maintain the temperature of the PBAA/AN in storage at 125°F plus or minus 5°F, and the other exchanger would be used to heat the PBAA/AN being added to the reactor from 125°F to 160°F.

## Consulting Engineers

Mr. Richard M. Gurney and Mr. James E. Tost had formed a partnership as consulting mechanical and electrical engineers in 1958. The major portion of their work was mechanical and electrical design of industrial plants and large buildings such as schools, hotels, etc. The mechanical design included specifications of heating and air conditioning units which required heat transfer calculations to size the units and air ducts. Such selections of mechanical equipment were based on the predicted performance and the best economic yield as far as original price and expected maintenance was concerned. "It is important," said Mr. Gurney, "in the layout of piping, for instance, to route the pipe so that the function of each pipe is apparent; in this way the plant would be easier to operate and fewer mistakes would be made by closing the wrong valve."

[1] In the company's vernacular, a "Design Criteria" consisted of a written description of the process and equipment necessary to create and materialize a product; complete with written plans for engineering and fabrication of a product, including figures on specific details, such as temperature limits and viscosity.

By 1962 the firm of Gurney and Tost employed seven design engineers, four layout draftsman, two secretaries, besides two partners. The office and drafting rooms covered about 3,000 square feet.

An initial meeting was scheduled between Mr. Parson, Mr. Gart, Mr. Gurney, and Mr. Tost to discuss the amount budgeted by Allied for this addition to the premix facility and to discuss the Design Criteria with Mr. Gart, the project engineer, for this addition. The objective of the consulting engineer would be to produce a set of drawings and specifications for the premix facility that were clear and concise so that when the job was bid and built, there would be a minimum number of questions as to the design intent.

The partners then determined the magnitude of the fee to be charged for their engineering services. Customarily, this fee is a fixed percentage of the bid for the mechanical and electrical contract for the construction of the building or facility, but can also be a fixed fee as it was in this case. This fixed fee was negotiated by Mr. Gurney and Mr. Tost with Allied, in the person of Mr. Parson, and a contract was signed.

The first step in the generation of the drawings and specifications for the premix facility was to initiate a process flow diagram. This diagram illustrated schematically the entire process and would be used during the design to check continuity and assure everyone concerned that a critical piece of equipment had not been omitted. This schematic diagram would also be used to locate control valves, thermocouples, fluid level recorders, etc. Finally, this diagram would be used to establish that all the points of the Design Criteria had been considered. This schematic was initiated by Mr. Robert Olsen, and as the general arrangement of equipment became fixed, Robert was able to perform some of the heat loss calculations to establish insulation thickness on pipes and the PBAA/AN storage tanks.

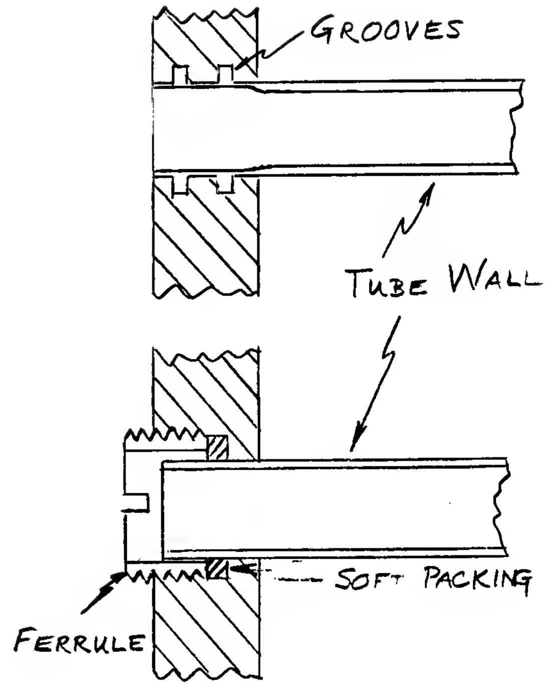
## The Problem

Mr. Gurney who had been doing some of the calculations for sizing of the mechanical equipment while Robert was generating the flow diagram asked Robert to determine whether the proposed heat exchanger was adequate to heat the PBAA/AN from 125°F to 160°F as it was being pumped from the storage tanks to the reactor. The PBAA/AN would be heated by water circulating through a rack of Chromolox electric heaters (See Exhibit 2B).

Mr. Frank Howard of the B. C. Dooley Company had proposed an 1800 series single pass, counterflow heat exchanger, containing 421 tubes, 5/8 inch O.D. x 18 BWG.* The pitch of the tubes was triangular and was 25/32 inches. The baffles were 25% cut and the baffle pitch was 3-1/2 inches. Mr. Howard had suggested a tube length of eighteen feet. Mr. Gurney asked Robert to determine if the heat transfer area were adequate and if it were, what would be the fouling factor. The handbook data that Robert thought he might need appears in the appendix.

* (18 BWG - 0.527 dia. inside)

# APPENDIX



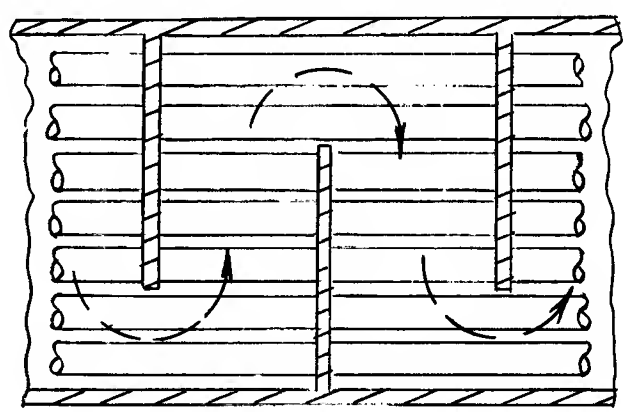

## Shell and Tube Heat Exchangers

A "Shell and Tube" type of heat exchanger is used where large heat transfer surfaces are required. Shell and tube equipment involves expanding a tube into a tube sheet and forming a seal that does not leak under normal operating conditions. These tubes can also be fixed to the tube sheet using a ferrule and a soft metal packing ring.

Tube holes cannot be drilled very close together because the tube sheet would not be able to support the load. The shortest distance between the tubes is called the clearance. The layout for tube sheets is fairly standard, using either a triangular or square pitch. Shells are fabricated from steel pipe; the wall thickness depends on the operating pressure

## Baffles

The heat transfer coefficient is greater when the liquid is turbulent. Baffles are commonly used in shell and tube exchanges to cause the liquid to flow through the shell normal to the axis of the tubes. The center to center distance between the baffles is called the baffle pitch. The maximum baffle spacing is equal to the diameter of the shell and the minimum is one-fifth of the shell diameter.



SEGMENTAL BAFFLE

The most common type of baffles are the segmental baffles shown in the above sketch. The height of these baffles are generally 75% of the I.D. of the shell so they are called 25% cut baffles.

Shell-side Film Coefficients

The heat transfer coefficients outside tube bundles are referred to as shell-side coefficients. When baffles are employed to direct the shell side fluid from top to bottom, the heat transfer coefficient is higher than that for undisturbed flow along the tube bundle.

The closer the baffle spacing, the more often the fluid flows across the bundle so the fluid is more turbulent, but the pressure drop in the shell side of the exchanger increases. In addition to the effects of the baffle spacing, the shell-side coefficients are also affected by the type of tube pitch, tube size, clearance, and fluid flow characteristics.

There is no true flow area across the tube bundle; however, this flow may be correlated with fluid flowing tubes by using a heat transfer factor ($j_H$) as suggested by McAdams.[1] (Exhibit 3B is a correlation of industrial data which gives satisfactory results for hydrocarbons, organic compounds, water, acqueous solutions, and gases.

The linear and mass velocities of the fluid change continuously across the bundle, since both the width of the flow area and the number of tubes change across the shell. The width of the flow area represented in Exhibit 4B is that at the center of the shell and the length is equal to the baffle spacing. The tube pitch ($P_t$) is the sum of the tube diameter and the clearance (C'). If the inside diameter of the shell is divided by the tube pitch, this yields fictitious numbers of tubes that exist in the center of the shell. The shell side area $a_s$ is given by:

$$a_s = \frac{ID \times C'B}{P_t \times 144} (FT^2)$$

Where:

ID - Shell inside Dia. (in.)
C' - Clearance between tubes (in.)
B - Baffle spacing (in.)
$P_t$ - Tube Pitch (in.)

and the mass velocity is:

$$G_s = \frac{W}{a_s} lb/(HR)(FT^2)$$

where W is the weight of hot fluid, (lb/HR).

Since the flow of fluid on the shell side is partially along and partially across the axis of the tubes, the true hydraulic radius cannot be employed; however, excellent agreement is obtained if the hydraulic radius is calculated along the axis of the tubes rather than across the tubes. The equivalent diameter for the shell is then taken as four times the hydraulic radius obtained for a particular tube pattern.

[1] McAdams, W. H., Heat Transmission, 2nd Edition, McGraw-Hill, p. 217.

For a triangular pattern:

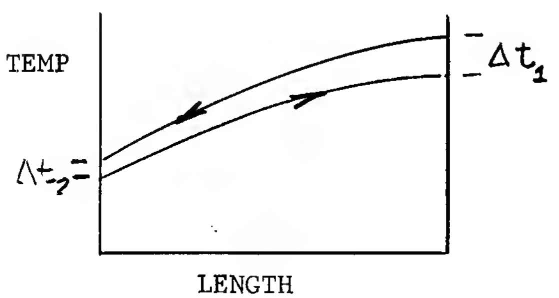
$$d_e = \frac{4\left[\frac{1}{2}P_t \times 0.86P_t - \frac{1}{2}\pi d_o^2/4\right]}{\pi/2\ (d_o)}$$

where $P_t$ is the tube pitch (in.) and $d_o$ is the tube outside diameter (in.).

Temperature Difference

If the temperature difference at one end of the heat exchanger is not more than fifty per cent greater than the temperature difference at the other end, the arithmetic mean temperature difference will be within one per cent of the logarithmic mean temperature difference. If the ratio of $\Delta t_1/\Delta t_2$ is greater than 1.5, the error in the arithmetic mean as a measure of the temperature difference increases rapidly. The logarithmic mean temperature difference is:

$$(\text{LMTD}) = \left[\Delta t_1 - \Delta t_2 \Big/ \left(\ln\left[\Delta t_1/\Delta t_2\right]\right)\right] \qquad \text{Where } \Delta t_1 > \Delta t_2$$




Where $\Delta t_1$ - Larger temp. difference

$\Delta t_2$ - Smaller temp. difference

One assumption made in the derivation of (LMTD) was that the overall heat transfer coefficient U was constant. However, in a shell and tube heat exchanger, the viscosity of both fluids are changing as they pass through the exchanger. Thus, the U at the hot terminal would be greater than that at the cold terminal.

One may consider this variation of U by numerical integration of $d_q$, the heat transferred over incremental lengths of pipe dL, and using the average values of U from point to point in the differential equation:

$$d_q = U_{AVERAGE}(dL)\Delta t$$

This is a time consuming method and the increase in the accuracy of the result does not warrant the effort.

A method has been developed (See Reference 1, p. 94) assuming that U is linear with temperature and then deriving an expression for the true temperature difference accordingly. The ratio of LMTD for constant U and the true temperature difference for varying U is then used as a basis for establishing a single overall coefficient which is the true mean rather than the arithmetic mean overall heat transfer coefficient.

Average or Caloric Temperature

The caloric temperature of the hot fluid may be determined from the following relationship:

$$T_c = T_2 + F_c (T_1 - T_2)$$

where:

$T_c$ - caloric temperature of the hot fluid (°F)

$T_2$ - hot fluid outlet temperature (°F)

$T_1$ - hot fluid inlet temperature (°F)

$F_c$ - caloric fraction

Likewise, the caloric temperature of the cold fluid may be determined from a similar relationship.

$$t_c = t_1 + F_c (t_2 - t_1)$$

where:

$t_c$ - caloric temperature of the cold fluid (°F)

$t_1$ - cold fluid inlet temperature (°F)

$t_2$ - cold fluid outlet temperature (°F)

$F_c$ - caloric fraction

The caloric temperature ($t_c$) is the temperature of the cold fluid at which $h_i$ and $h_o$ are computed and at which such a value of true mean overall heat transfer coefficient exists.

These equations state that by multiplying the temperature rise of the controlling (film) stream by $F_c$ and adding the resulting fractional rise to the final temperature of the stream, a temperature is obtained at which the film coefficients $h_i$ and $h_o$ and overall heat transfer coefficient U may be determined.

The fraction $F_c$ may be evaluated using the following relationship or using Exhibit 4B:

$$F_c = \frac{\left(1/K_c + [r/(r-1)]\right)}{1 + \dfrac{\ln(K_c + 1)}{\ln r}} - 1/K_c$$

where: $F_c$ - caloric fraction

$K_c$ - $\dfrac{U_h - U_c}{U_c}$

$U_h$ - overall heat transfer coefficient at the hot terminal

$U_c$ - overall heat transfer coefficient at the cold terminal

$r$ - $\Delta t_c/\Delta t_h$

$\Delta t_c$ - temperature difference at the cold terminal (°F)

$\Delta t_h$ - temperature difference at the hot terminal (°F)

If neither of the liquids are very viscous at the cold terminal, not more than 1 cps, if the temperature ranges do not exceed 50 to 100°F and if the temperature difference is less than 50°F, the arithmetic means of $T_1$ and $T_2$, $t_1$ and $t_2$ may be used in place of $T_c$ and $t_c$ for evaluating the physical properties. For nonviscous fluids,

$\phi = (\mu/\mu w)^{0.14}$ may be taken as unity.

## Analysis of Heat Exchanger

In determining the necessary heat transfer area between the hot water and the colder PBAA/AN, one must determine the film coefficients on the inside and outside of the heat exchanger tubes. From the film coefficients, the clean overall heat transfer coefficient may be obtained. Finally, the design overall heat transfer coefficient may be determined, and knowing the temperature difference and the amount of heat to be transmitted, the necessary heat transfer area may be realized.

## Tube (Cold) Side

Knowing the number, the outside diameter, and the gauge of the tubes and the physical characteristics of the PBAA/AN, Reynolds' number may be determined for the tube side fluid. Using Exhibit 5B and knowing Reynolds' number ($R_e$) and the length over diameter ratio of the tubes,

the heat transfer factor ($j_h$) may be obtained. The inside heat transfer coefficient may then be realized by using the following empirical relationship.

$$h_i = j_h \left( \frac{h}{D} \right) \left( \frac{C_p \mu}{h} \right)^{1/3} \left( \frac{\mu}{\mu_w} \right)^{0.14}$$

Where:

$h_i$ = inside heat transfer coefficient (BTU/HR - $Ft^2$ - °F)

$j_h$ = heat transfer factor (Exhibit 5B) (dimensionless)

$k$ = fluid conductivity (BTU/HR - $Ft^2$ - °F)

$D$ = diameter or equivalent diameter (Ft)

$C_p$ = specific heat (BTU/lb - °F)

$\mu$ = viscosity at the caloric temperature, centipoise x 2.42 = (lb/Ft - HR)

$\mu_w$ = viscosity at the tube wall temperatures, centipoise x 2.42 = (lb/Ft - HR)

If the material being heated or cooled is viscous, a value of $h_i$ may not be obtained since $\mu_w$ is not known; however, one may determine $(h_i/\phi_t)$, where $\phi_t = \left(\mu/\mu_w\right)^{0.14}$. The t refers to the tube side.

The heat transfer area of a shell and tube type heat exchanger is usually taken as the outside area of the tubes. The above coefficient ($h_i$) refers to the inside area and may be converted to the outside area by the following relationship:

$$\frac{h_{io}}{\phi_t} = \frac{h_i}{\phi_t} \times \frac{I.D.}{O.D.}$$

where $h_{io}$ - film coefficient referred to the outside of the tube.

$\phi_t$ - ratio of $(\mu/\mu_w)^{0.14}$ referred to the tubes.

Shell Side

Referring to the shell side once again, knowing $a_s$, $G_s$ and $d_e$, the Reynolds' number may be obtained for the hot fluid. The value of $j_H$ may be evaluated using Exhibit 3B, and $h_o$ may be determined using the relationship to evaluate $h_i$, using the properties of the shell side fluid. If $\phi_w$ is not known, the value of $(h_o/\phi_s)$ may be evaluated. The s refers to the shell side.

The tube wall temperature may now be determined using the following relationship:

$$t_w = t_c + \frac{h_o/\phi_s}{h_{io}/\phi_t + h_o/\phi_s}(T_c - t_c)$$

where:

$t_w$ - tube wall temperature

$\phi_s$ - ratio of $(\mu/\mu_w)^{0.14}$ referred to the shell side.

The value of $\mu_w$ may now be obtained and $\phi_t$ and $\phi_s$ evaluated.

Overall Coefficient

The clean overall coefficient ($U_{cl}$) may be obtained from the following relationship:

$$U_{cl} = \frac{h_{io} \times h_o}{h_{io} + h_o} \text{ (BTU/HR - FT}^2\text{ - °F)}$$

Design Coefficient and Dirt Factor

$$U_D = \frac{q}{A\Delta t}$$

where:

q - total heat transferred (BTU/HR)
A - actual area of the heat exchanger ($Ft^2$)
$\Delta t$ - the calculated temperature difference (°F)

The design coefficient refers to the selection of a particular heat exchanger since the area is the only unknown factor in the equation.

The resistance to the transfer of heat will increase as the exchanger is used due to the collection of dirt and scale on the surfaces of the exchanger tubes. The additional resistance may be anticipated by increasing

the area for heat transfer; this may be accomplished by employing a dirt or fouling factor.

$$R_d = \frac{U_{c1} - U_D}{U_c U_d} \text{ (HR)(Ft}^2\text{)(°F)/BTU}$$

*　　　*　　　*　　　*　　　*

Additional Information

PBA/AN - 50 GPM (mass flow)

| Temp. (°F) | μ Centipoise | Specific Gravity | Conductivity (k) |
|---|---|---|---|
| 160 | 2900 | 0.905 | 0.075 |
| 125 | 5200 | 0.919 | 0.075 |

Water - 50 GPM

| Temp. (°F) | Conductivity (k) |
|---|---|
| 190 | 0.408 |
| 160 | 0.397 |

Shell inside diameter is 18 inches.

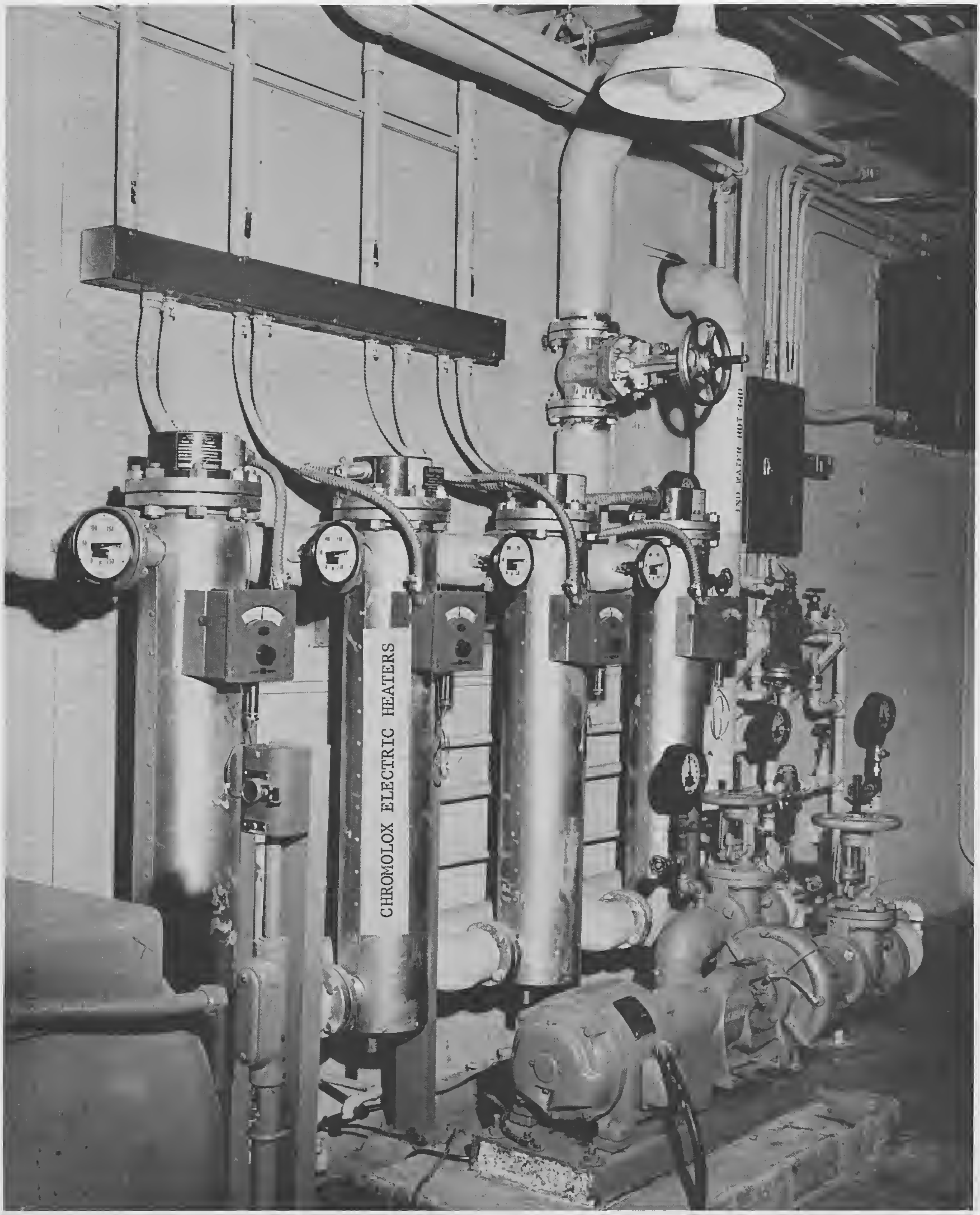
## REFERENCES

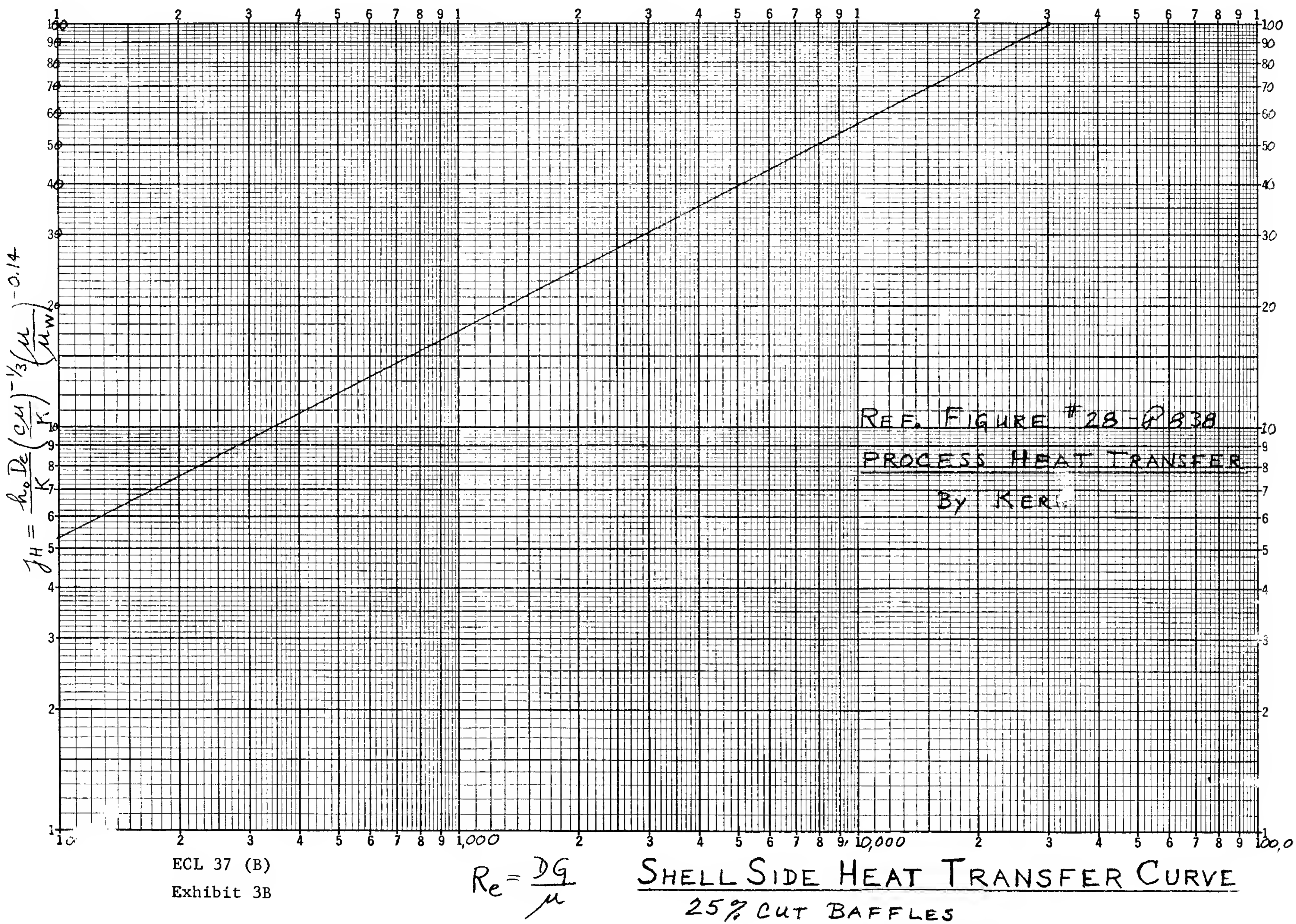
1. D. Q. Kern, Process Heat Transfer, McGraw-Hill, 1950.


ECL 37 (B)
Exhibit 1B

ECL 37 (B)

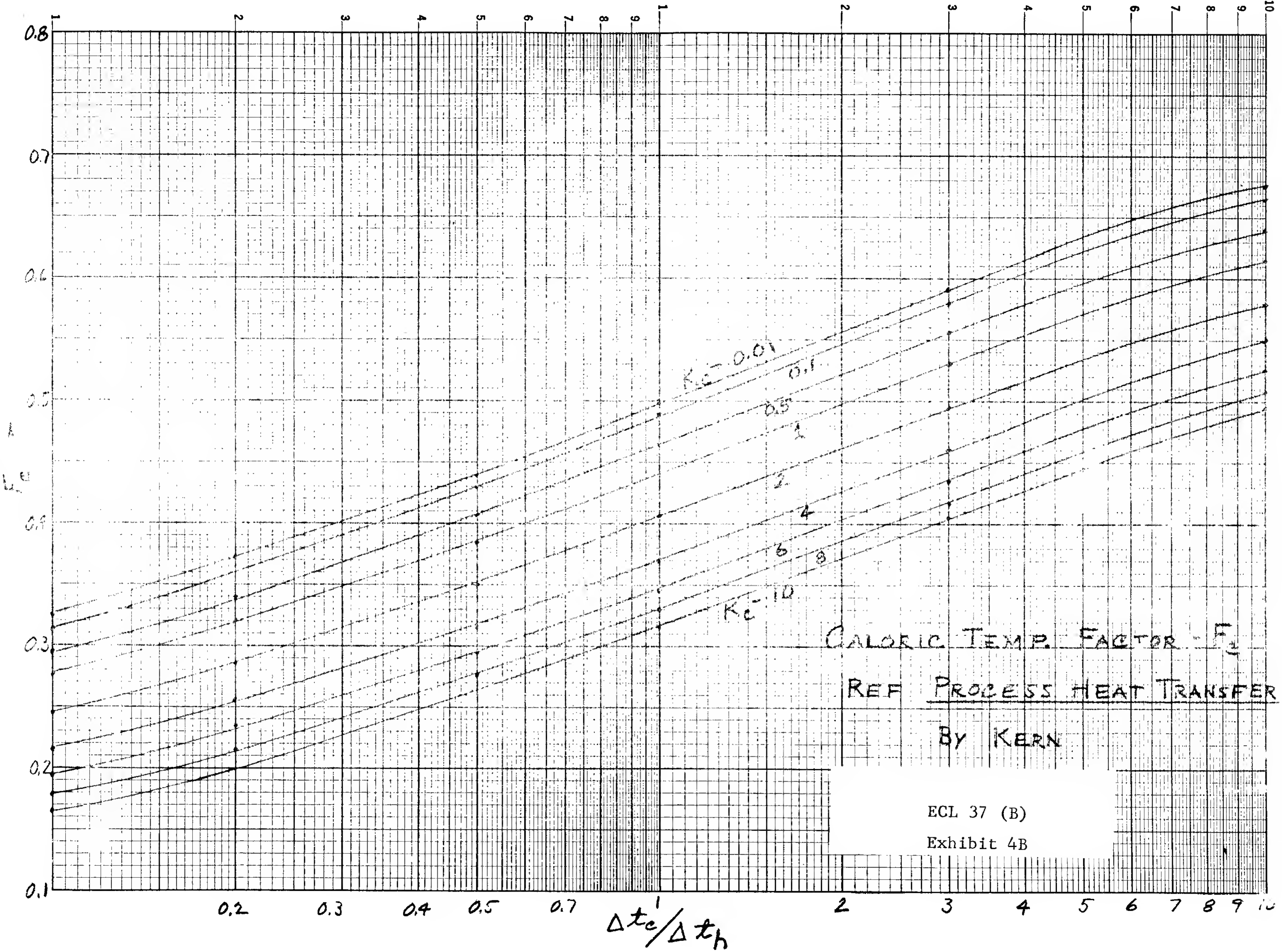
Exhibit 2B





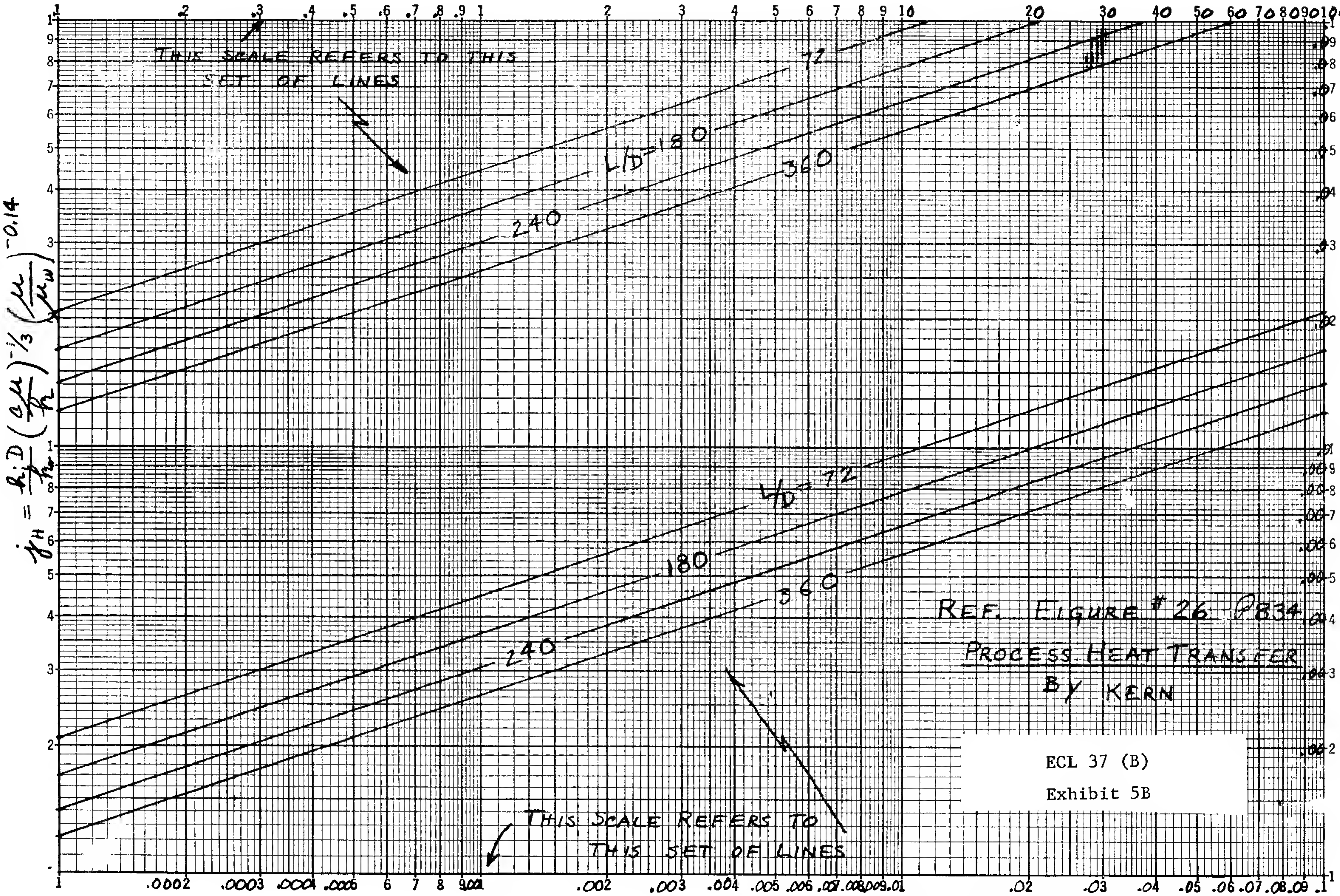

ECL 37 (B)
Exhibit 3B

SHELL SIDE HEAT TRANSFER CURVE
25% CUT BAFFLES




ECL 37 (B)

Exhibit 4B




ECL 37 (B)

Exhibit 5B

$R_e = \frac{DG}{\mu}$ TUBE SIDE HEAT TRANSFER CURV

ALLIED SOLID ROCKET CORPORATION (C)

Having selected the heat exchangers, Mr. Gurney and Mr. Olsen had completed the equipment selection, except for the PBAA/AN pumps, and the flow diagram was also finished. The pumps could not be properly sized until the final detail piping drawings were almost completed so that the length and size of pipe, number of fittings, and valves could be ascertained. Mr. Gurney asked Robert Olsen to select a Waukesha positive displacement pump with appropriate motor speed and horsepower to move the PBAA/AN from the storage tanks to the reactor. These pumps would also be used to circulate the PBAA/AN in order to maintain the 125° plus or minus 5°F temperature in the storage tanks.

Mr. Gurney stated that if either the calculations or the schematic line diagram called for a change in the process not covered by the Design Criteria, the design engineer and Allied would meet to decide which route to take. Were a major change initiated, either the engineer or Allied could request that the fee be renegotiated.

A scaled layout was prepared by Mr. Peter Borne, a layout draftsman, working for Mr. Gurney. On this orthographic drawing, the pumps, valves, weigh stations, pipes, etc., were shown according to size and actual location on the job site. The information for this layout was obtained from the Design Criteria, the schematic line diagram, and the preliminary calculations performed by Mr. Gurney and Mr. Olsen.

Meetings were held weekly with Mr. Bill Gart and Mr. Dan Bensen of Allied and Mr. Richard Gurney and Mr. Robert Olson of Gurney and Tost. The purpose of these meetings was to clarify any questions that arose as the schematic line diagram and the layout were being prepared. These meetings kept Allied informed of the progress of the design work.

Mr. Gurney and Mr. Olsen selected the type of controls and the location of the central console for most efficient process operation. Because of the severe explosion hazard, pneumatic process controls were used for most of the systems. Where special electric or electronic characteristics were indicated, explosion-proof devices were selected.

As the layout approached completion, a print was made and this was "red-lined"[1] by Mr. Gurney to indicate the areas for which details would be required. The more complicated details would be done by the layout plan or a draftsman under his direct supervision. The layoutman or Robert would prepare rough sketches of the detail and have the draftsman generate the complete picture.

[1] "red-lined" - Circle an area or piece of equipment with a red pencil.

The equipment selection could now be confirmed since the actual lengths of pipes, number and types of fittings, had been shown on the layout; thus, the rough calculations might be confirmed.

The equipment might be shown either on a schedule sheet that was used specifically for this purpose or might be shown on each of the drawings. When the drawings were almost complete, three sets of prints were made and one set was submitted to Bill Gart of Allied for the final approval. These drawings were returned to Mr. Gurney in two days with a few notes and requested changes. Because of the frequent meetings between Allied representatives and the consulting engineer, Mr. Gart was aware of the progress of the work, so the few changes noted on the drawings were relatively minor.

The second set of prints was used by an estimator, Mr. Ed Fraser, working for Mr. Gurney who listed the equipment and material from the drawings to be used on the addition to the premix facility. Ed then estimated the labor to install this equipment and associated piping and, knowing the prevailing wage schedule, was able to arrive at a total cost of equipment, construction, and installation. This confirmed the budget figure set by Allied at the initial meeting.

The third set of prints was used by Robert Olsen to perform the final check of all the drawings. Robert said that this was a difficult and pains-taking job. Usually, a yellow pencil is used to note the items and equipment that have been checked and found correct. The missing items and items in error were noted in red pencil. Robert said, "Sometimes it appears as though I had bled all over the drawing, and the fellow who generated the drawing certainly doesn't appreciate it."

Since the detail drawings were almost complete, the selection for the PBAA/AN pump could be made. Bob thought that the "storage to reactor" loop would have the highest pump head, (See Exhibits 1C and 2C), so his next step was to select a Waukesha positive displacement pump to furnish the operating speed of this pump and its horsepower.

A positive displacement pump will deliver a capacity that is proportional to the speed at which it is running. Three types of impellers are employed in the Waukesha pumps, single, double, and triple; however, the standard is the twinblade impeller which provides a balanced load on the shaft at all times. See Exhibit 4C through 6C for pump drawing performance charts.

Pressure Drop in Heat Exchanger

The following equation may be used to obtain the pressure drop in the tubes of the 1800 series heat exchanger:

$$\Delta p_t = \frac{fG_t^2 Ln}{5.22 \times 10^{10} D_e S \phi_t} \text{ psi}$$

where:

$\Delta p_t$ - pressure drop through the heat exchanger (psi)

$f$ - friction factor (sq.ft./sq.in.), (See E·hibit 7C)

$G_t$ - mass velocity in tubes ( /HR - FT$^2$)

$L$ - Length of tubes (ft)

$n$ - number of tube passes

$D_e$ - tube I.D. (ft)

$S$ - specific gravity of PBAA/AN (Exhibit 8C)

$\phi_t$ - $(\mu/\mu_w)^{0.14}$ - viscosity ratio

Robert determined that the pressure drop through the smaller heat exchanger (1300 series) was 26 psi for 50 gpm of PBAA/AN. The pressure drop due to the pipe and fittings from the 1800 series heat exchanger to the weigh hopper was calculated to be 9 psi.

Exhibit 9C lists some friction factors for pipe fittings that may be used to obtain the total pressure drop for the pump. The valves used on the PBAA/AN line are a special type and contribute one psi per valve to the line loss.

ECL 37 (C)
Exhibit 1C

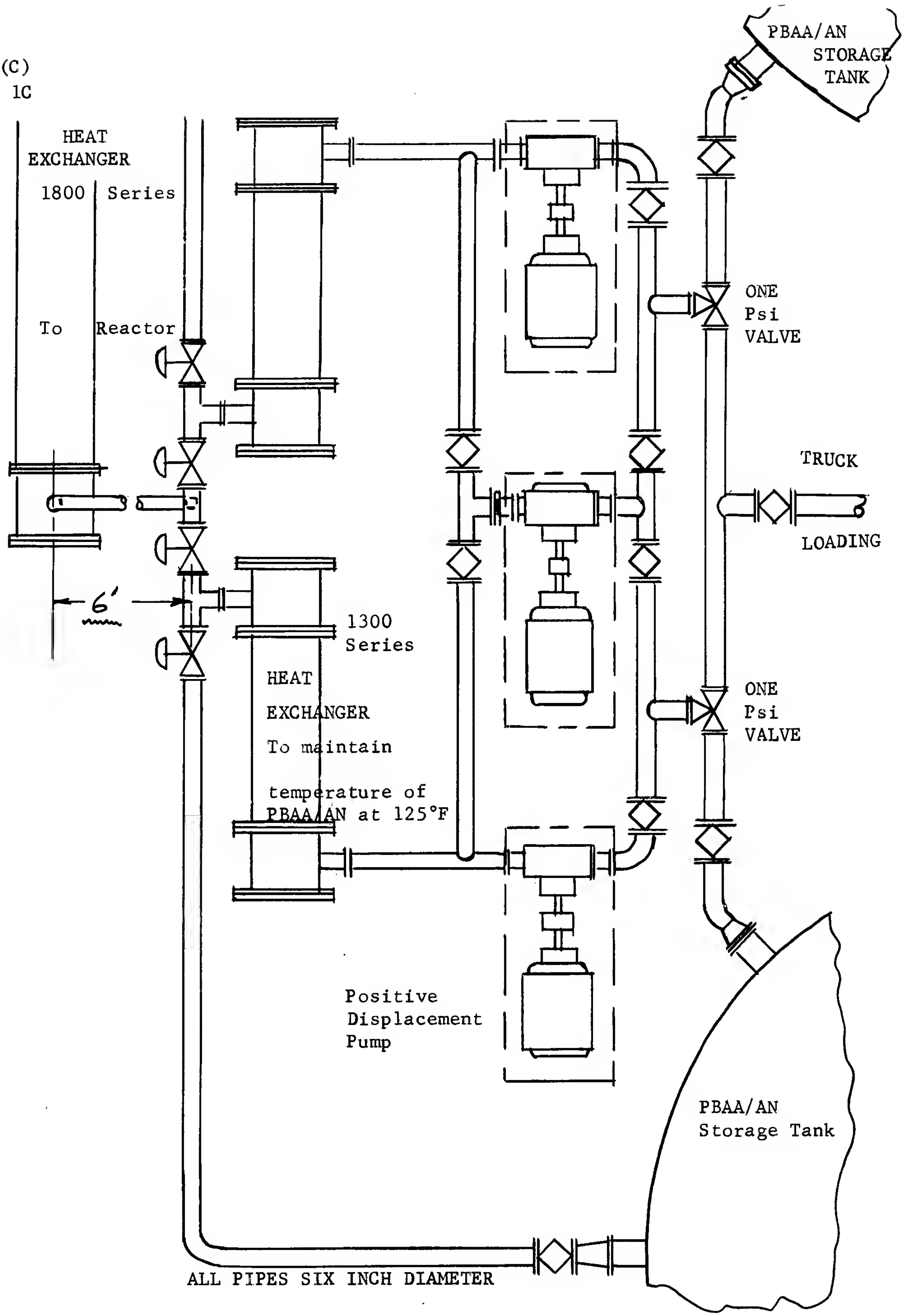



EXHIBIT 1C - PLAN VIEW
SCALE - 3/8" = 1'-0"

ECL 37 (C)
Exhibit 2C

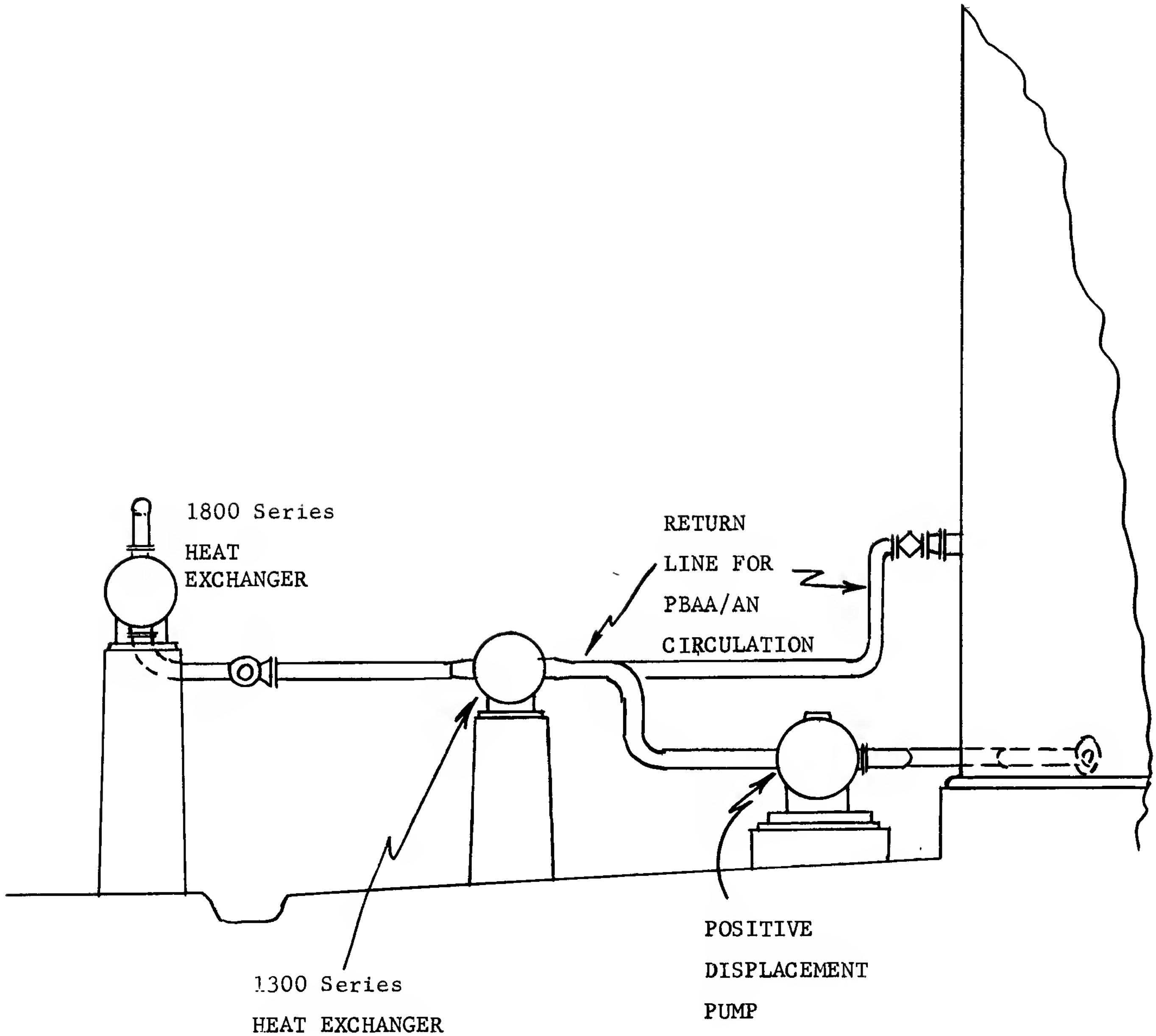



EXHIBIT 2C - ELEVATION VIEW

SCALE - 3/8" = 1'-0"

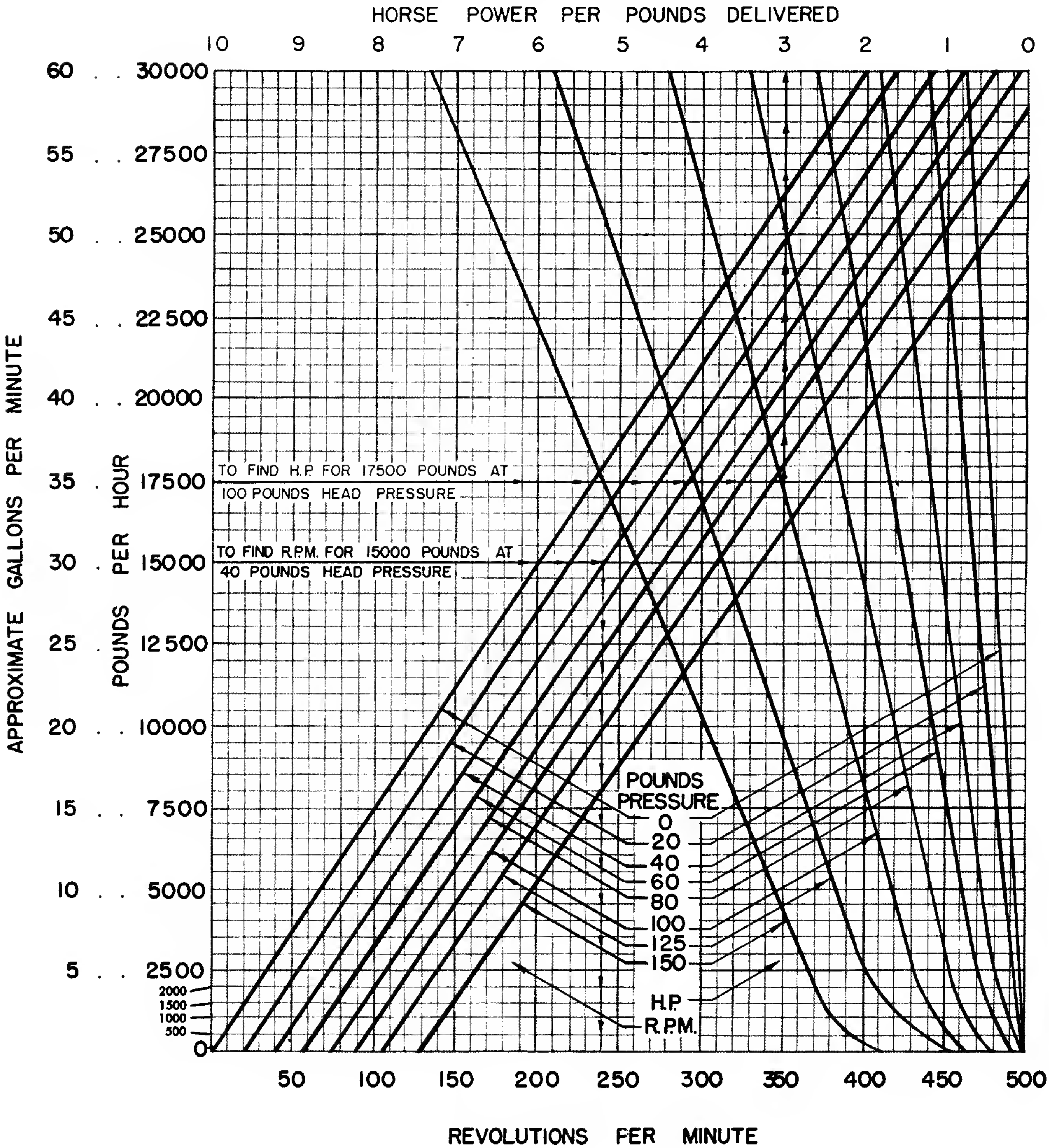
ECL (C)
Exhibit 4C

## NO. 55 2" SIZE

### WAUKESHA POSITIVE DISPLACEMENT PUMP

**No. 55 Pump Displacement is 15.0 Gallons per 100 RPM at 0 PSI — Specific Gravity 1**

*This Graph Applicable for Metal or Rubber Impeller Pumps.*
*Maxmium recommended head pressure for Rubber Impeller Pumps — 100 PSI.*






Litho in U.S.A. DLC 61

# Performance Charts

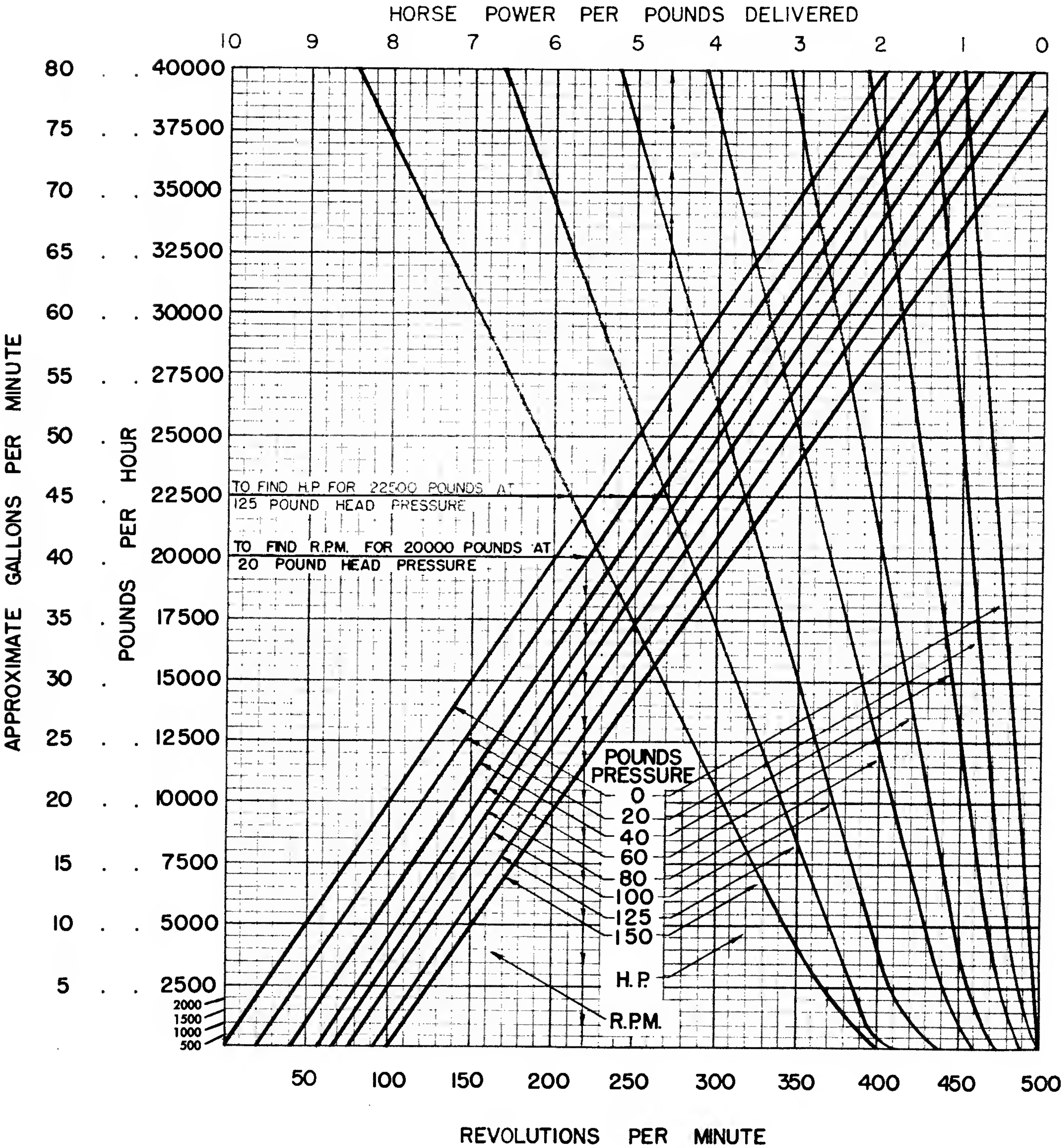


## NO. 100 2" SIZE

### WAUKESHA POSITIVE DISPLACEMENT PUMP

**No. 100 Pump Displacement is 19.0 Gallons per 100 RPM at 0 PSI — Specific Gravity 1**

*This Graph Applicable only to Metal Impeller Pumps.*
*Rubber Impeller Pumps not available in this size.*



# Performance Charts

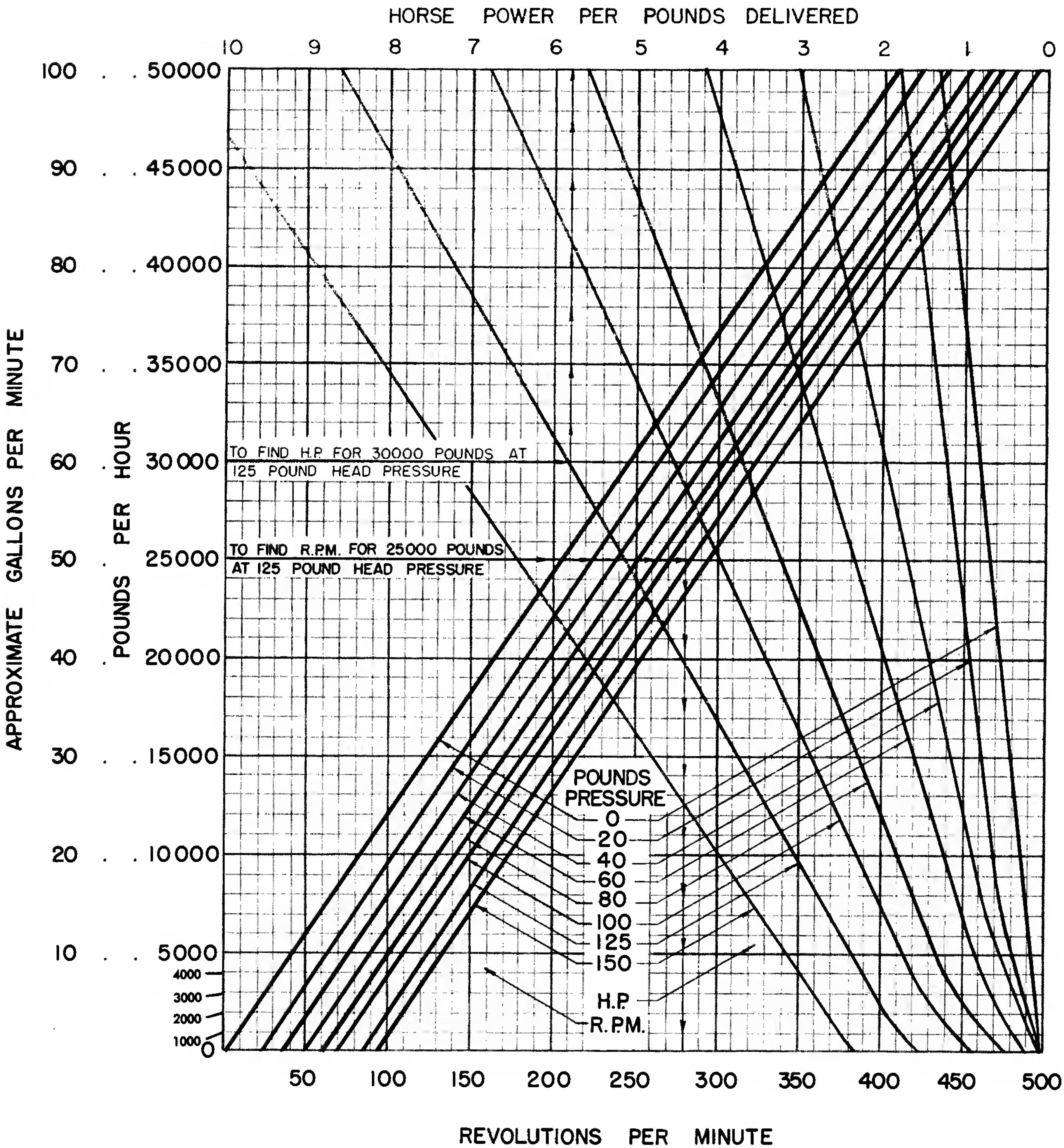
ECL (C)
Exhibit 6C

## NO. 125 2½" SIZE

### WAUKESHA POSITIVE DISPLACEMENT PUMP

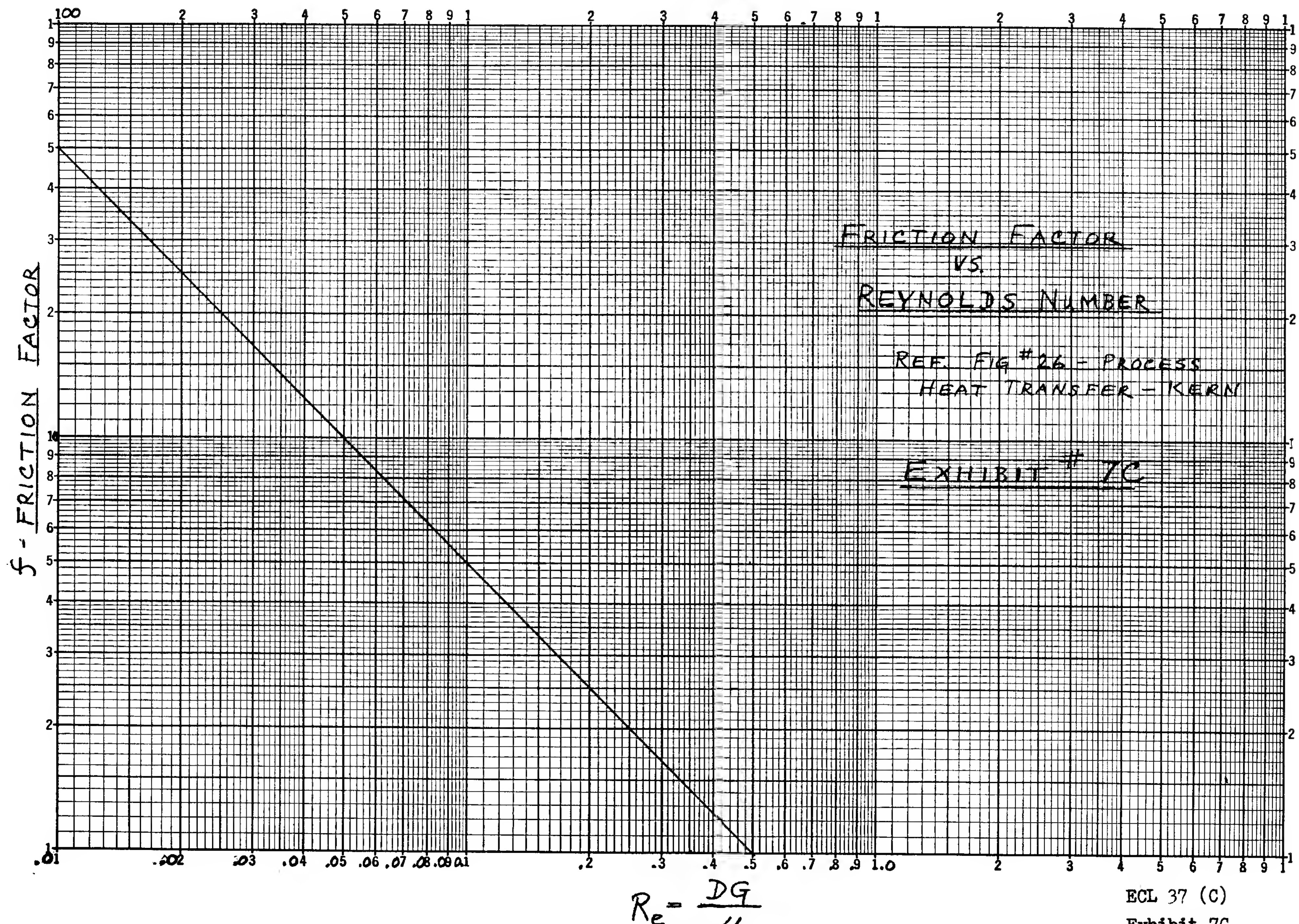
**No. 125 Pump Displacement is 23.3 Gallons per 100 RPM at 0 PSI — Specific Gravity 1**

*This Graph Applicable for Metal or Rubber Impeller Pumps.*
*Maxmium recommended head pressure for Rubber Impeller Pumps — 100 PSI.*






Litho in U.S.A. DLC 61




ECL 37 (C)
Exhibit 7C

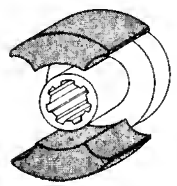
A Waukesha P.D. (Positive Displacement) pump will deliver a capacity that is proportional to the speed at which it is running, for example, a 25 DO pump has a capacity range of from 0 to 24 gallons per minute. Therefore, the pump could be set at a speed (See performance graph Page 57) to deliver any capacity within the 0-24 GPM range that may be required. Maximum pump operating temperature—225°F.

The sizes and capacities of Waukesha Pumps are listed as follows:

**Capacity At 20 P.S.I.**

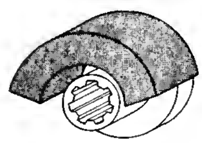
| Size Pump | Gallons per Minute | | Pounds per Hour | |
|---|---|---|---|---|
| | Min. | Max. | Min. | Max. |
| 2 BB—1" | 0 | 3 | 0 | 1500 |
| 10 DO—1½" | 0 | 10 | 0 | 5000 |
| 25 DO—1½" | 0 | 24 | 0 | 12000 |
| 55 DO—2" | 0 | 60 | 0 | 30000 |
| 100 DO—2" | 0 | 80 | 0 | 40000 |
| 125 DO—2½" | 0 | 100 | 0 | 50000 |
| 200 DO—4" | 0 | 300 | 0 | 150000 |

## WAUKESHA PUMP IMPELLERS

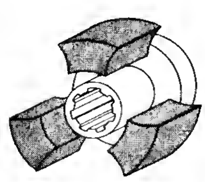


Three types of Impellers are available. However, the standard is the twin-blade impeller which provides a balanced load on the shaft at all times.

Modifications of the impellers are used when the pumps are used on specific applications where the twin-blade impeller would be detrimental to the pumping ability of the pump.

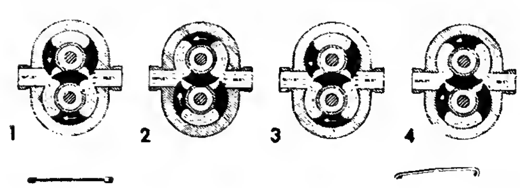


**Single Blade Impeller**—used when products containing particles that cannot be broken up are pumped. Example, large curd cottage cheese, chili, cherry and strawberry preserve, meat pie filling, etc. Single bladed impellers may be installed in pumps with double blade impellers without making any modifications.



**Triple-Blade Impeller** — These Impellers are used on 25DO tank truck pump only. They were designed to minimize the noise level produced by hydraulic shock when the pump was operated at elevated speeds with the twin blade type. Triple blade impellers may be interchanged with twin blade without changing the shafts.

## Diagram of Product Flow Action



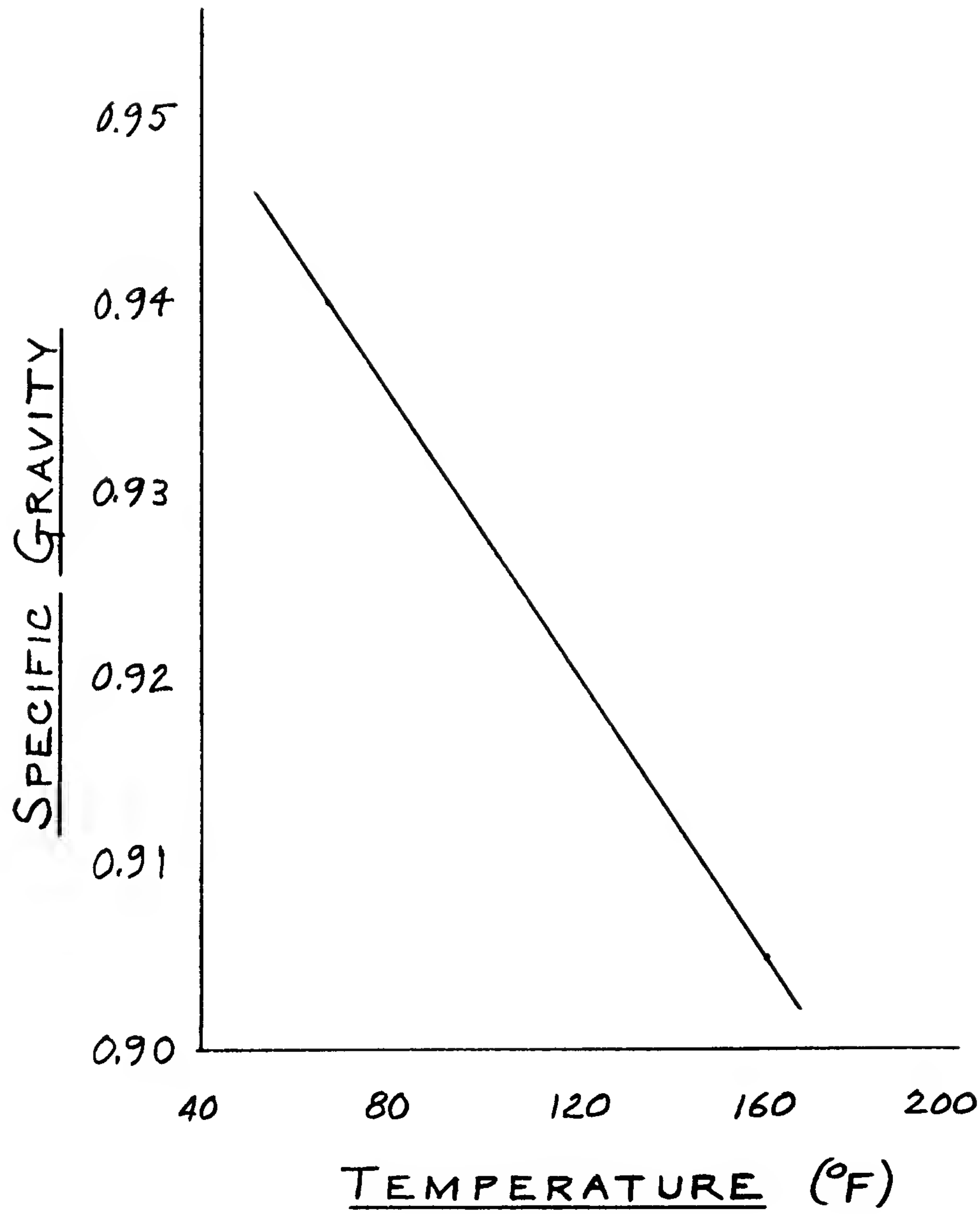



Exhibit 8C: Specific gravity vs. temperature for PBAA/AN

## Schedule (Thickness) of Steel Pipe Used in Obtaining Resistance Of Valves and Fittings of Various Pressure Classes by Test*

| Valve or Fitting ASA Pressure Classification (Steam Rating) | | Schedule No. of Pipe (Thickness) |
|---|---|---|
| 250-Pound and Lower | | Schedule 40 |
| 300-Pound to 600-Pound | | Schedule 80 |
| 900-Pound | | Schedule 120 |
| 1500-Pound | | Schedule 160 |
| 2500-Pound | Sizes ½ to 6-inch | xx (Double Extra Strong) |
| | Sizes 8-inch and larger | Schedule 160 |

*These schedule numbers have been arbitrarily selected only for the purpose of identifying the various pressure classes of valves and fittings with specific pipe dimensions for the interpretation of flow test data; they should not be construed as a recommendation for installation purposes.

## Representative Equivalent Length‡ in Pipe Diameters (L/D) Of Various Valves and Fittings

| Description of Product | | | | Equivalent Length In Pipe Diameters (L/D) |
|---|---|---|---|---|
| Globe Valves | Conventional | With no obstruction in flat, bevel, or plug type seat | Fully open | 340 |
| | | With wing or pin guided disc | Fully open | 450 |
| | Y-Pattern | (No obstruction in flat, bevel, or plug type seat) | | |
| | | – With stem 60 degrees from run of pipe line | Fully open | 175 |
| | | – With stem 45 degrees from run of pipe line | Fully open | 145 |
| Angle Valves | Conventional | With no obstruction in flat, bevel, or plug type seat | Fully open | 145 |
| | | With wing or pin guided disc | Fully open | 200 |
| Gate Valves | Conventional Wedge Disc, Double Disc, or Plug Disc | | Fully open | 13 |
| | | | Three-quarters open | 35 |
| | | | One-half open | 160 |
| | | | One-quarter open | 900 |
| | Pulp Stock | | Fully open | 17 |
| | | | Three-quarters open | 50 |
| | | | One-half open | 260 |
| | | | One-quarter open | 1200 |
| | Conduit Pipe Line | | Fully open | 3** |
| Check Valves | Conventional Swing | | 0.5†...Fully open | 135 |
| | Clearway Swing | | 0.5†...Fully open | 50 |
| | Globe Lift or Stop | | 2.0†...Fully open | Same as Globe |
| | Angle Lift or Stop | | 2.0†...Fully open | Same as Angle |
| | In-Line Ball | | 2.5 vertical and 0.25 horizontal†...Fully open | 150 |
| Foot Valves with Strainer | | With poppet lift-type disc | 0.3†...Fully open | 420 |
| | | With leather-hinged disc | 0.4†...Fully open | 75 |
| Butterfly Valves (6-inch and larger) | | | Fully open | 20 |
| Cocks | Straight-Through | Rectangular plug port area equal to 100% of pipe area | Fully open | 18 |
| | Three-Way | Rectangular plug port area equal to 80% of pipe area (fully open) | Flow straight through | 44 |
| | | | Flow through branch | 140 |
| Fittings | 90 Degree Standard Elbow | | | 30 |
| | 45 Degree Standard Elbow | | | 16 |
| | 90 Degree Long Radius Elbow | | | 20 |
| | 90 Degree Street Elbow | | | 50 |
| | 45 Degree Street Elbow | | | 26 |
| | Square Corner Elbow | | | 57 |
| | Standard Tee | With flow through run | | 20 |
| | | With flow through branch | | 60 |
| | Close Pattern Return Bend | | | 50 |
| Pipe | 90 Degree Pipe Bends | | | See Page A-27 |
| | Miter Bends | | | See Page A-27 |
| | Sudden Enlargements and Contractions | | | See Page A-26 |
| | Entrance and Exit Losses | | | See Page A-26 |

**Exact equivalent length is equal to the length between flange faces or welding ends.

†Minimum calculated pressure drop (psi) across valve to provide sufficient flow to lift disc fully.

‡For limitations, see page 2-11.

*For resistance factor "K", equivalent length in feet of pipe, and equivalent flow coefficient "$C_v$", see pages A-31 and A-32.*